AN INVESTIGATION INTO LOCAL AIR QUALITY THROUGHOUT TWO RESIDENTIAL COMMUNITIES BISECTED BY MAJOR HIGHWAYS IN SOUTH AUCKLAND, NEW ZEALAND

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE
OF
DOCTOR OF PHILOSOPHY
IN ENVIRONMENTAL SCIENCE
BY

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Frontispiece

Homes situated alongside State Highway 1, Otahuhu, South Auckland. Illegal refuse burning takes place in the background. Winter, 2010.

Acknowledgements

Having spent quite some time at the University of Canterbury's Department of Geography, it is somewhat difficult to finally be leaving. Naturally there have been many academic staff who have inspired me over the years and countless support staff who have been instrumental in my success. These include, but are not limited to: Professor Andy Sturman, Professor Eric Pawson, Dr Garth Cant, Dr Malcolm Campbell, Dr Chris Gomez, Dr Tim Appelhans, Anna Petrie, Marney Brosnan, Kathy Hogarth, John Thyne, Graham Furniss, Paul Bealing, Justin Harrison, Nick Key, and of course, my thesis supervisors, Professor Simon Kingham and Associate Professor Peyman Zawar-Reza. Professor Jason Tylianakis from the School of Biological Sciences deserves a special mention. Jason has been a good friend over the years and has happily offered me independent advice at various stages throughout my postgraduate study.

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Abbreviations

AADT	Annual Average Daily Traffic	
AER	Air Exchange Rate	ac/hr
AERMOD	American Meteorological Society/Environmental Protection Agency Regulatory Model	
ANOVA	Analysis of Variance	
APEX	Air Pollution EXposure Model	
AVOC	Aromatic Volatile Organic Compound	
BAM	Beta Attenuation Monitor	$\mu g/m^3$
BC	Black Carbon	ng/m^3
BS	Black Smoke	
BTEX	Benzene, toluene, ethylbenzene and xylenes	ppb
CAU	Census Area Unit	
CHAD	Consolidated Human Activities Database	
CO	Carbon monoxide	$\mu g/m^3$, ppm
CO_2	Carbon dioxide	$\mu g/m^3$, ppm
CPC	Condensation Particle Counter	pt/cm^3
DEFRA	Department for Environment, Food and Rural Affairs (UK)	
DPM	Diesel Particulate Matter	
EC	Elemental Carbon	$\mu g/m^3$
EMI	Exposure Model for Individuals	
EPA	Environmental Protection Agency (US)	
EXPOLIS	Air Pollution Exposure Distributions of Adult Urban Populations in Europe	
ExPOSITION	Exposition (Exposure-Position) Model	
FEM	Federal Equivalent Method - US-EPA Certified Measurement Instrument	
GIS	Geographical Information System	
GLM	Generalised Linear Model	
GPS	Global Positioning System	
HAPEM	Hazardous Air Pollution Exposure Model	
HOA	Hydrocarbon-like Organic Aerosol	
IDW	Inverse Distance Weighting	
NAAQS	National Ambient Air Quality Standards	
NIWA	National Institute of Water and Atmospheric Research	

NO	Nitrogen oxide	µg/m^3, ppb
NO_2	Nitrogen dioxide	µg/m^3, ppb
NO_x	Mono-nitrogen oxides (nitric oxide and nitrogen dioxide)	µg/m^3
NO_y	Reactive nitrogen oxides	µg/m^3
NZTA	New Zealand Transport Agency	
LUR	Land Use Regression Model	
O_3	Ozone	µg/m^3
OC	Organic Carbon	
OK	Ordinary kriging	
PAH	Polycyclic Aromatic Hydrocarbon	
pPAH	Particle-bound Polycyclic Aromatic Hydrocarbon	
PM	Particulate Matter	µg/m^3
$PM_{1.0}$	Particulate matter less than 1 µm in diameter	µg/m^3
$PM_{2.5}$	Particulate matter less than 2.5 µm in diameter	µg/m^3
PM_{10}	Particulate matter less than 10 µm in diameter	µg/m^3
PNC	Particle Number Count	pt/cm^3
pNEM	probabilistic National Exposure Model	
RSP	Respirable Particles	
SES	Socioeconomic Status	
SHEDS	Stochastic Human Exposure and Dose Simulation	
SMPS	Scanning Mobility Particle Sizer	nm, pt/cm^3
SO_2	Sulphur dioxide	ppm
SO_4	Sulphate	
TAPM	The Air Pollution Exposure Model	
TPM	Traffic-emitted Particulate Matter	µg/m^3
UFP	Ultrafine particles less than 100 nm in diameter	pt/cm^3
US-EPA	United States Environmental Protection Agency	
VKT	Vehicle Kilometres Travelled	
VOC	Volatile Organic Compound	
WHO	World Health Organization	

Preface

This thesis is the result of natural progression on from the candidate's Master's thesis titled *'Cyclist exposure to traffic pollution: microscale variance, the impact of route choice and comparisons to other modal choices in two New Zealand cities*'. With this work, the author developed much of the background atmospheric knowledge and base skill set required to carry out the extensive field sampling, data processing and analyses presented throughout this Doctoral thesis. The Master's year of 2009 also gave ample opportunity to dream up original research ideas for future projects, should the opportunity ever arise. In early 2010, the National Institute of Water and Atmospheric Research (NIWA), funded by the Land Transport Agency, decided to undertake the largest air quality sampling campaign ever conducted in New Zealand. This was to have a special focus on traffic emissions near highways and based on previous experience, the author was gratefully invited to participate.

The project was to take place in South Auckland alongside State Highway 1 and to a lesser extent, State Highway 20. These areas were primarily chosen for their flat, non-complex terrain and good site accessibility for the placement of sampling instrumentation trailers close to the highways. The objectives were straightforward; conduct detailed air quality observations, validate roadside dispersion models and enable and extend health impact assessments. Finding a suitably engaging research angle to explore came courtesy of the local communities which happened to reside alongside these two highways. I was never much interested in the pure physical science of environmental degradation but more the social consequences of our actions. If these are better understood, especially in regard to human health, perhaps society's motivation to mitigate negative environmental impacts will improve. As the highways have progressively widened over the years, they have encroached to such an extent in these communities that some houses are situated less than 5 metres from the roadway edge. Since these communities are among the poorest in New Zealand, a large number of homes are in sub-standard condition and are consequently prone to heightened infiltration of air pollutants and traffic noise. I wondered about who lived there and what they thought about living right next to one of New Zealand's busiest roads; I wondered how I could shape my research in a way that might somehow serve them, even if only marginally beneficial. I knew that there were potential long-term health effects of living within close proximity to high-volume roads. I knew that there was increasing momentum in the Environmental Justice (EJ) arena overseas; that is, working to ensure the poor are not disproportionately exposed to levels of urban pollution. I knew that very little work had been done on systematically quantifying local neighbourhood variation in air quality and I knew hardly anything had been done in New Zealand. Thence I set out to combine all of these research aspects together in one coherent thesis, where each chapter logically builds on the next. It was to be quite simple - measure the effects, discover who lives there, see if they are unfairly exposed and find out what they actually think about the issue.

> "*If a measurement matters at all, it is because it must have some conceivable effect on decisions and behaviour. If we can't identify a decision that could be affected by a proposed measurement and how it could change those decisions, then the measurement simply has no value"* Douglas W Hubbard, 2007.

This thesis differs substantially in its scope, when compared to most science theses pertaining to urban air quality, as the emphasis tends to be on physical measurements and numerical modelling alone. This thesis encompasses: an extensive long-term measurement campaign employing mixed sampling methods; physical processes of air pollution, from basic atmospheric chemistry to emissions transport and dispersion modelling; targeted, community-based semi-structured interviewing; modelling of personal exposure to emissions concentrations; various statistical models, but also qualitative analysis; geospatial analyses, and the mapping of both pollutant concentrations and social data.

Preface to Chapter Two

Chapter two provides a background literature review and follows on from the introductory chapter. It is divided into six core sections which follow the order in which they are introduced throughout the chapters in this thesis. These are: health impacts, roadside gradients, environmental justice, neighbourhood variation, daily personal exposure and community perceptions of air quality.
The literature review aims to provide a slightly critical overview of the wide variety of published physical, health and social science articles which comprise the basis for current understandings of population exposure to traffic pollution. In doing so, the hope is to demonstrate where there are knowledge gaps for which further research is required. The review includes table summaries of 106 published articles from 1977 - 2014 with accompanying discussion throughout.

Preface to Chapter Three

This chapter is entitled 'Air quality and resident demographics across the local study areas' and has been submitted for publication with the title of 'Near-highway air quality at two socioeconomically disparate residential suburbs'. While both residential study areas feature a six-lane highway, one has substantially higher traffic volumes and a much poorer population. This chapter aims to provide an overview of both areas by comparing traffic data and meteorology, in addition to roadside and background pollutant concentrations. Finally, local resident demographics such as ethnicity, income and deprivation level are compared.

Preface to Chapter Four

This chapter, entitled 'Microspatial assessment of neighbourhood air quality' was published with the title of 'Using mobile monitoring to visualise diurnal variation of traffic pollutants across two near-highway neighbourhoods'. It employs a bicycle monitoring platform to map and visualise diurnal variation of the spatial extent of roadway emissions, throughout the full extent of the study communities. The goal was to assess how far the substantially elevated near-highway concentrations (identified in chapter one) extended into the residential community and whether the spatial extent differed between early mornings, daytime periods and late at night.

Preface to Chapter Five

Chapter five, titled 'Personal exposure modelling to assess the importance of residential proximity to the highway' aimed to quantify the ambient exposure impact of living at various distances upwind and downwind of the highway. It was submitted for publication with a near-identical title. This work uses a current US-EPA population exposure model that was specially adapted for application in this South Auckland study. It is the first time this model has been applied to a study area outside of the USA and the first time this type of model has been used to explore the implications of varying residential distance from highways. In addition to proximity and position of the home relative to the highway, the effects of occupation, commute distance and work location, are also explored. The primary goal was to identify which types of individuals would receive the greatest long-term exposure benefits of a buffer distance between the highway and their home location.

Preface to Chapter Six

The final core chapter of this thesis is entitled 'Proximity to busy highways and resident perceptions of air quality' and has been accepted for publication with the same title. Its purpose is to build upon the understandings of the physical air quality processes and population exposure learnt from the investigations carried out in the previous chapters. The aim was to provide an additional layer that would render some level of understanding surrounding the social side of traffic emissions exposure. Local individuals' perceptions and understandings are explored as a function of residential proximity to the highways using multivariate linear regression. Additional discussion is made within the context of open-ended discussion points raised throughout the interview process. This provides new insight into how both positive and negative perceptions differ with proximity to traffic emissions.

Abstract

Population exposure to traffic pollution is a rapidly developing, multi-disciplinary scientific field. While the link between long-term exposure and respiratory issues is well-established, there are probable links to a number of more serious health effects, which are still not fully understood. In the interests of protecting human health, it is prudent that we take a cautionary approach and actively seek to reduce exposure levels, especially in the home environment where people spend a significant portion of their time. In many large cities, a substantial number of homes are situated on land immediately adjacent to busy freeways and other heavily-trafficked roads. Characterising exposures of local residents is incredibly challenging but necessary for advancing epidemiological understandings. While existing studies are plentiful, the results are mixed and generally not transferable to other urban areas due to the localised nature of the built environment and meteorological influences. This thesis aimed to employ a variety of methods to develop a holistic understanding of the influence of traffic emissions on near-highway residents' exposure in two communities of South Auckland, New Zealand, where Annual Average Daily Traffic (AADT) is as high as 122,000 vehicles. First, ultrafine particles (UFPs), nitrogen oxides (NO_x), carbon monoxide (CO) and particulate matter ≤ 10 µm (PM_{10}) were continuously monitored using a series of fixed stations at different distances from the highways, over several months during the winters of 2010 and 2011. Emissions modelling output (based on traffic composition), was used within a dispersion model to compare modelled concentrations with monitored levels. In addition, community census meshblock units were mapped by level of social deprivation in order to assess potential inequities in highway emissions exposure. The second layer of local air quality investigation involved using a bicycle platform to systematically measure concentrations of UFPs, CO and PM_{10} using the entire street-grid network throughout each community. This was done forty times - five times at four times of day (07:00, 12:00, 17:00 and 22:00), for each study area, with the aim of mapping the diurnal fluctuation of microspatial variation in concentrations. Using global positioning system (GPS) data and geographical information system (GIS) software, spatially-resolved pollutant levels were pooled by time of day and the median values mapped, providing a visualisation of the spatial extent of the influence of emissions from the highways compared to minor roads. The third layer involved using data from multiple ambient monitors, both within the local areas and around the city, to simulate fifty-four residents' personal exposure for the month of June, 2010. This required collecting time-activity information which was carried out by door-to-door surveying. The time-activity data were transformed into microenvironment and activity codes reflecting residents movements across a typical week, which were then run through the US-EPA's Air Pollution Exposure Model (APEX). APEX is a probabilistic population exposure model for which the user sets numerous microenvironmental parameters such as Air Exchange Rates (AERs) and infiltration factors, which are used in combination with air pollutant concentrations, meteorological, and geospatial data, to calculate individuals' exposures. Simulated exposure outputs were grouped by residents' occupations and their home addresses were artificially placed at varying distances from the highways. The effects of residential proximity to the highway, occupation, work destination and commute distance were explored using a Generalised Linear Model (GLM). Surveyed residents were also asked a series of Likert-type, ordered response questions relating to their perceptions and understandings of the potential impacts of living near a significant emissions source. Their response scores were explored as a function of proximity to the highway using multivariate linear regression. This formed the final layer of this investigation into air quality throughout these South Auckland communities of Otahuhu and Mangere Bridge. Results show that concentrations of primary traffic pollutants (UFPs, NO_x, CO) are elevated by 41 - 64% within the roadside corridor compared to setback distances approximately 150 m away and that the spatial extent of UFPs can reach up to 650 m downwind early in the morning and late in the evening. Further, social deprivation mapping revealed that 100% of all census meshblocks within 150 m either side of both highways are at the extreme end of the deprivation index (NZDep levels 8 - 10). Simulations for residents dispersed across the community of Otahuhu estimated daily NO_x and CO exposure would increase by 32 and 37% (p<0.001) if they lived immediately downwind of the highway. If they were to shift 100 m further downwind, daily exposure would decline by 56 - 70% (p<0.001). The difference in individuals' exposure levels by occupation varied across the same distance by a factor of eight (p<0.05), with unemployed or retired persons the most exposed due to having more free time to spend outdoors at home (recreation, gardening, etc.). Those working in ventilated offices were the least exposed, even though ambient concentrations - likely due to a strong urban street canyon effect - were higher than the nearest highway monitor (5 m downwind) by 25 - 30% for NO_x and CO, respectively. Inverse linear relationships were identified for distance from highway and measures of concern for health impacts, as well as for noise (p<0.05). Positive linear relationships were identified for distance from highway and ratings of both outdoor and indoor air quality (p<0.05). Measures of level of income had no conclusive statistically significant effect on perceptions (p>0.05). The main findings within this thesis demonstrate that those living within the highway corridor are disproportionately exposed to elevated long-term average concentrations of toxic air pollutants which may impact on physical health. While the socioeconomic characteristics could also heighten susceptibility to potential health impacts in these areas, certain activity patterns can help mitigate exposure. This thesis has also shown that there may be quantifiable psychological benefits of a separation buffer of at least 100 m

alongside major highways. These results enhance a very limited knowledge base on the impacts of near-roadway pollution in New Zealand. Furthermore, the results lend additional support to the international literature which is working to reduce residential exposures and population exposure disparities through better policies and improved environmental planning. Where possible, the placement of sensitive population groups within highway corridors, e.g. retirement homes, social housing complexes, schools and childcare centres, should be avoided.

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Please indicate the chapter/section/pages of this thesis that are extracted from co-authored work and provide details of the publication or submission from which the extract comes:

Chapter three is based on the following publication:

Pattinson, W, Zawar-Reza, P, Longley, I & Kingham, S 2014, 'Near-highway air quality at two socioeconomically disparate residential suburbs', Under review in *International Journal of Environment and Pollution*

Please detail the nature and extent (%) of contribution by the candidate:

The original idea for the paper included contributions from the co-authors. The candidate wrote a complete (100%) first draft of the manuscript. Comments resulting in minor edits were the result of advice by the co-authors. Dr Zawar-Reza performed the initial setup and configuration of the dispersion model and the candidate ran, extracted and analysed the model output. All spatial analyses and map production was performed by the candidate. The candidate contributed no less than 90% of the total work required for this chapter.

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The undersigned certifies that:

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Chapter four is based on the following publication:

Pattinson, W, Longley, I & Kingham, S 2014, 'Using mobile monitoring to visualise diurnal variation of traffic pollutants across two near-highway neighbourhoods', *Atmospheric Environment*, vol. 94, pp. 782-92.

Please detail the nature and extent (%) of contribution by the candidate:

The original idea for the paper was the candidate's and included subsequent contributions from the co-authors. The candidate wrote a complete (100%) first draft of the manuscript. Comments resulting in minor edits were the result of advice by the co-authors and then minor revisions requested by the peer-reviewers (~10% of the total wording). All spatial analyses and map production was performed by the candidate. The candidate contributed no less than 90% of the total work required for this chapter.

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Please indicate the chapter/section/pages of this thesis that are extracted from co-authored work and provide details of the publication or submission from which the extract comes:

Chapter five is based on the following publication:

Pattinson, W, Langstaff, J, Longley, I & Kingham, S 2014, 'Using an ambient air pollution exposure model to explore the impact of local residents' proximity to a major highway', Under review in *Air Quality, Atmosphere and Health*

Please detail the nature and extent (%) of contribution by the candidate:

The original idea for the paper was the candidate's and included subsequent contributions from the co-authors. The candidate wrote a complete (100%) first draft of the manuscript. Comments resulting in minor edits were the result of advice by the co-authors. John Langstaff provided advice and help with the exposure model configuration, including customisation of the modelling software for the purposes of this research paper. All exposure modelling, statistical analyses and map production was performed by the candidate. The candidate contributed no less than 90% of the total work required for this chapter.

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Please indicate the chapter/section/pages of this thesis that are extracted from co-authored work and provide details of the publication or submission from which the extract comes:

Chapter six is based on the following publication:

Pattinson, W, Longley, I & Kingham, S 2014, 'Proximity to busy highways and local resident perceptions of air quality in South Auckland, New Zealand', Under review in *Health & Place*

Please detail the nature and extent (%) of contribution by the candidate:

The original idea for the paper was the candidate's. The candidate wrote a complete (100%) first draft of the manuscript. Comments resulting in minor edits were the result of advice by the co-authors. Survey design, statistical analyses and map production was performed by the candidate. The candidate contributed no less than 90% of the total work required for this chapter.

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1. Chapter One: Introduction

1.1 Opening statement

Emissions from heavily-trafficked roadways have been shown to negatively impact on human health. To what extent remains largely unclear, but it is likely to be a major contributing factor across a broad range of both minor and very serious health effects. In the interests of protecting human health, exposure science seeks to understand the concentrations and chemical compositions of exhaust pipe emissions, as well as non-exhaust particulate as a result of mechanical wear and roadway re-suspension (from turbulence generated by moving vehicles).

Throughout the world's cities, thousands of people live adjacent to major highways and are exposed to elevated concentrations where they spend a substantial portion of their time. While buildings provide some protection, older homes are particularly prone to the infiltration of outdoor air and many who live in these locations cannot afford expensive ventilation systems and some simply prefer natural ventilation. These are locations where people raise families, battle illness and grow old, and some spend their entire lifetime in the same place.

Considering the world's reliance on fossil fuels, there is no overnight solution. Until such time that combustion engines are fully replaced with better technology, and that there is a higher patronage of public transport and greener freight solutions, we will continue living in unhealthy urban atmospheres. In the interim, it is important that the scale of the issue of emissions exposure is at least well-understood.

This thesis aims to make a contribution to the existing knowledge base by conducting a broad investigation into the impacts of six-lane highways on local pollutant levels. Specifically, it aims to assess how far these impacts extend into the communities - both in a physical manner (pollutant concentrations) and in a social sense (local residents' perspectives).

1.2 Local research context

This research took place in South Auckland, New Zealand. Auckland is New Zealand's largest city, covering approximately 1000 km^2, and has a population of close to 1.5 million. Compared to other cities of similar population, Auckland is very spread out and the majority of housing consists of single-storey detached dwellings, rather than high density apartment style living. Auckland has several highways which carry at least 80,000 vehicles per day. Two of these pass through South Auckland. This research is based in two communities which are bisected by these highways - Otahuhu (State Highway 1) and Mangere Bridge (State Highway 20). These areas in close proximity to one another, with Otahuhu to the east and Mangere Bridge to the west (Figure 1.1).

Figure 1.1 Local research areas showing highways and main monitoring sites

1.3 Thesis objectives

The overarching aim of this thesis is to conduct a broad enquiry into local air quality within these communities, using a mixture of methods concerning both physical and social aspects.

Five major objectives are defined:

1. To assess levels of traffic pollutant concentrations at the roadside corridor and further back, using fixed-site monitors and dispersion modelling, for a sustained monitoring period

2. To briefly assess whether there is a possible case of environmental injustice at the highway edge; that is, what is the deprivation level of these census meshblocks, compared to further back from the road?

3. To systematically map near-highway traffic pollutant gradients and street-to-street concentrations to achieve spatial saturation for the purposes of assessing intra-suburban variation, using a non-polluting vehicle

4. To explore the importance of residential proximity (to the highway) and occupation on medium-term, average daily pollutant exposure

5. To gain insights into local resident perceptions of living within a highway corridor and to assess whether there are any spatial gradients regarding concern

Although vehicles emit a large suite of air toxics, the objectives are explored using a limited number of key traffic pollutants and one pollutant representative of urban background. The traffic pollutants are ultrafine particles (UFPs), nitrogen oxides (NO_x) and carbon monoxide (CO). These were selected as UFPs, NO_x (including both NO and NO_2) and CO are by far the most commonly measured and modelled pollutants of vehicular origin across the literature base; they are the leading preferred markers of fresh exhaust emissions. Particulate matter ≤ 10 µm (PM_{10}) is most representative of the urban background plume, consisting of numerous sources such as industry and wood burning for home heating, with a limited traffic-source component. In contrast to ultrafine particles and gases emitted from vehicles, which tend to sharply decline away from roadways, PM_{10} levels are often spatially homogenous across large urban areas. PM_{10} is included throughout this thesis investigation primarily for the purpose of comparison and contrast with the observations made for traffic emissions markers.

1.4 Thesis structure

The thesis structure follows logical evolution of a broad air quality investigation within a local community, beginning with standard fixed-site monitoring. These core measurements are then built on through the use of emissions dispersion modelling, spatial pollution mapping, personal exposure modelling and finally, personal perceptions of air quality. These methods of community air quality exploration are employed to construct a series of articles suitable for journal publication, which form the four main chapters within this thesis.

1.4.1 Academic publications

Table 1.1 details the academic publications included within this thesis. Each publication flows on from the next, aiming to meet the objectives in a clear and logical order.

Table 1.1 List of academic publications

Chapter	Publication Title	Objectives	Authors	Target Journal	Status
Three	Near-highway air quality at two socioeconomically disparate residential suburbs	1 & 2	Woodrow Pattinson, Peyman Zawar-Reza, Ian Longley, Simon Kingham	International Journal of Environment and Pollution	Past editorial office and under peer-review. Submitted 27/10/2013
Four	Using mobile monitoring to visualise diurnal variation of traffic pollutants across two near-highway neighbourhoods	3	Woodrow Pattinson, Ian Longley & Simon Kingham	Atmospheric Environment	Published in volume 94, pp. 782-92.
Five	Using an ambient air pollution exposure model to explore the impact of local residents' proximity to a major highway	4	Woodrow Pattinson, John Langstaff, Ian Longley & Simon Kingham	Air Quality, Atmosphere and Health	Accepted for publication pending revisions.
Six	Proximity to busy highways and local resident perceptions of air quality	5	Woodrow Pattinson, Ian Longley & Simon Kingham	Health & Place	Accepted for publication. *Article In Press*

In accordance with the University of Canterbury standards for the inclusion of publications within a thesis, the candidate is the first author and primary contributor for all papers. The candidate was responsible for no less than 95% of the analysis and for no less than 100% of the draft manuscript writing for any of the papers. Throughout the term of the PhD, the candidate also co-authored two other publications and presented work at multiple international conferences.

2. Chapter Two: Literature Review

2.1 Introduction

People living near freeways, or any area with high volumes of traffic, are said to be exposed to a host of toxic pollutants via the air that they breathe, which can potentially have quite serious consequences for health. Consequently, there is intense medical interest in the study of traffic pollution exposure and they easily outnumber all of the non-health traffic pollution publications combined. Any new epidemiological research that produces statistically significant associations which may be of interest to the general public is quickly sensationalised by mainstream media. '*Prenatal polycyclic aromatic hydrocarbon (PAH) exposure and child behaviour at age 6-7 years*' (Perera et al. 2012) becomes '*Mom's exposure to air pollution can increase kids' behaviour problems*' (Park 2012) in *Time* magazine. Similarly, '*Childhood cancer and traffic-related air pollution exposure in pregnancy and early life*' (Heck et al. 2013) becomes '*Car pollution linked to childhood cancers*' (Sifferlin 2013) - *Time* magazine. In actuality, what the original authors concluded from the latter was that there may be a weak association with traffic pollution exposure and that the study requires replication.

In some ways, the authors also do this within their own journal publications by inferring a significant finding within the publication title, noting the study weaknesses within the discussion and then exercising caution with any stated conclusions. Exposure science is incredibly complex and no single study is free of multiple limitations. There are countless issues relating to instrumentation, measurement approaches, modelling methods, covariate selection, spatial interpolation, spatio-temporal accuracy, participant surveying, clinical testing, quality assurance etc., which can lead to serious exposure misclassification. Possible misclassification is frequently acknowledged, as is potential confounding: "We cannot, however, rule out that confounders not accounted for or residual confounding could affect the results" (Sørensen et al. 2012, p. 743). Further, for every study which has reported a statistically significant association between traffic pollutant exposure and a particular health impact, there is likely to be one which did not find a link. This has led to critical reviews of the health literature; in some cases, where the authors are critically assessing publications they co-authored themselves. The issue at hand is whether there is enough evidence to confidently support a causal association - usually there is not. However, some links, such as the exacerbation of respiratory problems, are scientifically established beyond any level of doubt.

This literature review aims to take a slightly critical, but objective look at several of the key layers of research required to make population health assessments in relation to living near major sources of traffic pollution. After reviewing the health literature, it looks at studies which assess gradients away from highways (fixed-site measurements) and then how these gradients can lead to exposure inequity. This is followed by the latest research on spatial saturation techniques (assessing community or city-wide variation) and personal exposure modelling, which aims to significantly reduce exposure misclassification for epidemiological research. Finally, it reviews some of the social science literature on local resident perceptions of near-highway pollution. This literature review is structured so that each theme is introduced in the same order in which they appear throughout the four main chapters of this thesis - chapters 3, 4, 5 and 6. It also follows an 'inverted pyramid' structure, beginning with the larger knowledge bases and then channelling down to the more limited knowledge areas.

2.2 Methods

This literature review is primarily based on a series of tables created from a citation database and full-text journal article collection of ~800 articles developed by the candidate over a period of five-and-a-half years. Google Scholar and Science Direct were the main search engines used to update the collection over time, using keywords such as "near-highway" + "air quality" or "health effects". The studies included in this literature review are by no means an exhaustive list of traffic-pollution research, but are specially selected as the most relevant to each aspect of near-highway (or near-roadway) air quality explored throughout this thesis. With the exception of health effects studies (due to the sheer number), every relevant study found was included. All articles chosen for inclusion were read over (abstract, methods and conclusions as a minimum) and selected by the candidate, rather than taken from review articles by other authors. The exact criteria for choosing or excluding studies for each section are detailed in Table 2.1.1. Each research article appears in chronological order with the aim of giving the reader a clear impression of the evolution of the science and understandings. Some of the mean pollutant values were interpreted from charts provided in the articles and should be treated as approximations only. Similarly, where study area measurements e.g. distance from highway, study area size, number of traffic lanes, were not provided by the authors, these data were manually approximated using Google Earth. The purpose of completing these gaps was to ensure easy comparability between all of the research projects, the scale of each, and their conclusions.

Table 2.1 Criteria for inclusion or exclusion of studies summarised in the literature review

Table Number/s (Section)	Description	Pollutant focus	Criteria for inclusion or exclusion
All	-	Traffic emissions sources and pollutants in the general urban ambient mix, for which traffic makes a significant contribution	Studies where a major highway (or road with significant traffic volume) is present within the immediate study area, or within 500 m of the defined study area perimeter. A major highway is defined as any road with AADT ≥ 20,000 vehicles . One or two exceptions are made where meaningful results are reported for lesser-trafficked roads. Studies focusing on industrial emissions or urban background are excluded. Studies using LUR are not included except for those relating to health effects and environmental justice. Only original research studies are included; not findings from review or meta-analyses papers. All studies are published within reputable peer-reviewed journals. Exceptions are Master's or PhD theses of outstanding quality, suitable for publication.
2.2 (Section 2.3)	Near-highway health effects	Not required but focus is on traffic source exposure or proxy measures	Modelling studies using traffic metrics (no limit to spatial extent). Studies where health effects are measured by clinical testing, for any local population e.g. residents, students or workers, proximate to a major highway (within 500 m). Studies assessing the same illness or disease were limited to two to three each. With the exception of common respiratory issues, the focus was on healthy populations and studies assessing impacts on vulnerable subjects with pre-existing health conditions were excluded.
2.3, 2.4, 2.5, 2.6 (Section 2.4)	Near-highway decay	UFPs, NO_x, CO, PM_{10} (as within the current thesis)	At least three or more fixed-sampler or shifting mobile station measurements, situated in either direction from the highway's edge. Normally running across a single perpendicular transect.
2.7 (Section 2.5)	Environmental justice	Not required as traffic volume is a suitable proxy	Studies where possible issues of environmental injustice (in the context of traffic emissions exposure) are assessed for any near-highway area or area/s. No limit to spatial extent.
2.8 (Section 2.6)	Spatial saturation - fixed site	All traffic-source pollutants	At least three (preferably six) or more fixed-sampling or fixed-passive measurements situated throughout the study area. Preferably a dense network of monitors, or consisting of monitors spanning two or more transects perpendicular to the highway. Study area must feature at least some monitors within 1 km of one another.
2.9 (Section 2.6)	Spatial saturation - mobile	All traffic-source pollutants	Monitoring route must form a discernible grid and not consist of monitoring along a single road only. Preferably limited in spatial extent, but all within-city studies are included. Studies comparing inter-modal exposure along a non-grid type of route are excluded.
2.10 (Section 2.7)	Daily exposure to traffic pollutant concentrations	All traffic-source pollutants	All studies monitoring or modelling 24-hourly personal exposure to traffic emissions over a minimum of 5 days. Exposure models must account for multiple microenvironments as well as the individual's movements between them.
2.11 (Section 2.8)	Community perceptions of air quality	All traffic-source pollutants	All studies assessing community attitudes towards traffic emissions exposure, preferably with subjects living within a near-highway community.

2.3 Health impacts of traffic pollution on roadside communities

Central to the motivation for improving traffic pollutant measurements and personal exposure estimates, is the goal of improving understandings of the human health effects. Much of the early work on exposure to traffic emissions came as a result of understandings from occupational health studies. For example, the association between benzene exposure and leukaemia was established via studies of thousands of shoe factory workers in Turkey and China, from the mid-1960s through to the mid-80s (Aksoy 1985; Yin et al. 1996). This led to the study of exposure to benzene from gasoline, in workers such as mechanics, gasoline pump repairmen (Nilsson et al. 1996), and traffic policemen (Crebelli et al. 2001). It was later confirmed that benzene is a significant risk factor for leukaemia even with relatively low-level, acute exposures (Glass et al. 2003). These days, traffic emissions are associated with a very wide range of health afflictions ranging from minor respiratory problems through to premature birth, childhood developmental disorders, arthritis, cardiovascular disease, stroke, cognitive decline and various forms of cancer (Table 2.2). Naturally, the interest has evolved from occupational exposures to studying the effects of concentrations faced by regular urban citizens on a daily basis. Typically, the highest exposure dose received throughout a regular day will be during commuting, even if the commute is only a few minutes long (Fruin et al. 2008). However, there are millions of people whose exposure is substantially elevated by the fact they live alongside high-volume roads. Depending on how a residence is ventilated, indoor air quality can be just as poor as outdoor air, or even worse, as a result of infiltration and internal emissions sources. In the USA, Rowangould (2013) estimates 59.5 million people live within 500 m of roads with greater than 25,000 AADT. The majority of health studies have taken a population within a city or state and then regressed local health register data against traffic metrics such as proximity to roadways (Table 2.2). The problem with this approach is that it is extremely difficult to properly control for confounding health influences and there is also strong potential for exposure misclassification. Unless used in combination with other models, Land Use Regression (LUR) cannot account for time spent away from the exposure point, exposures while commuting and exposures at the workplace. Furthermore, LUR cannot account for the intake of toxic chemicals via other exposure pathways such as foods and cosmetics, which can be co-contributors to the same adverse health outcome being investigated.

The connections between near-highway residential exposures and health impacts are somewhat contentious. Published work will often face severe criticisms from other health researchers, in the form of letters to the editor (see Shukunami et al. 2006, for an example) and critical literature reviews. One of the most comprehensive critical reviews to date was conducted by the Health Effects Institute (HEI, 2010), a group consisting of some of the world's top exposure scientists and epidemiologists, some of whom co-authored multiple articles included in the review. The group scrutinised 275 articles and deemed 167 suitable for inclusion. A four-point scale of 'Strength of Causal Inference', ranging from 'No Causal Association' to 'Sufficient Evidence to Infer a Causal Association', was developed. The authors concluded that the only health impact for which there is sufficient evidence to infer causality, is the exacerbation of asthma in children; they found that the link to asthma incidence (new onset) and asthma prevalence in children was not yet sufficiently established by the research. Further, the association with adult asthma and health care utilisation for respiratory problems (both adults and children) was classed as 'Inadequate and insufficient'. The reasons for this were not only that around half of the studies reported no heightened odds ratios (with traffic proximity, compared to further back), but for those that did, there were clear methodological shortfalls.

Perhaps the most compelling conclusion from the HEI review was that there is insufficient evidence to infer any causative link whatsoever to all forms of cancers, in both children and adults. Again, the authors found issues with adequately controlling for confounders, such as parental occupations and smoking behaviours, in one study linking benzene (from traffic emissions) to childhood leukaemia (Raaschou-Nielsen et al. 2001, as cited by HEI 2010). Another key problem with the traffic emissions-cancer association is that the exposure science literature often refers to mutagenic studies where animals are exposed to very high concentrations which would not ever be experienced by humans under normal circumstances, except for in poorly controlled occupational settings. Hence it is quite a stretch to extrapolate any of the findings from animal studies or from occupational studies such as Aksoy's (1985), to those for comparably lower-level exposures to traffic emissions.

A raft of other serious health problems were ranked as 'Suggestive, but not sufficient' (to infer a causal link). These included all-cause mortality, cardiovascular disease, myocardial infarction, atherosclerosis, lung function and the exacerbation of respiratory symptoms. In the four years since the HEI's review paper, the evidence strengthening these associations has grown with further replication and improved methodologies. For example, a nine-year study in Vancouver reported a clear linear relationship between long-term black carbon exposure and cardiovascular disease (Gan et al. 2011). A community-based study in Boston, focusing on residents living within the first 450 m of a major freeway (AADT 150,000), identified associations between proximity and elevated cardiovascular disease risk (Brugge et al. 2013). Instead of using roadway proximity and traffic metrics as proxies for exposure, they measured concentrations throughout the community for 55 days, and then followed up with participant surveying and field clinics over the course of two years.

Most recently, studies have brought attention to newly identified associations with childhood health effects. These include autism, attention deficit, anxiety issues and obesity (Chiu et al. 2013; Perera et al. 2012; Rundle et al. 2012; Volk et al. 2013, see Table 2.2). One of these studies, on attention deficit, anxiety issues and depression, took place in the Bronx, NY (Perera et al. 2012). Although a positive association was found (PAH exposure, $p<0.05$), its authors raised a common limitation in that unmeasured influences of other environmental pollutants may have contributed to confounding. Further, this cohort consisted entirely of African-American and Dominican children. This raises the question of whether there may be any genetic, dietary, or cultural factors that are not accounted for in the statistical models; although in this particular study, dietary PAH intake was considered via participant questionnaire and found to be a non-significant predictor. Lastly, exposure measured at the home environment cannot account for other microenvironments in which they spend their time - both the work and commute-to-work environments can be significant exposure sources.

Another important potential confounder for near-roadway research is the influence of noise and stress associated with proximity to heavy traffic. Noise, vibrations, dust re-suspension and traffic accidents can all cause additional stress on top of any obvious air quality impacts such as fumes, haze and soot. For some, the psychological effects can be more detrimental to health than any long-term physical impacts from emissions exposure. These effects can be stronger for those who have the additional stress of concern for children or vulnerable family members (Jakovljevic et al. 2009). In a Danish study by Sørensen et al. (2012), NO_x concentrations were found to be correlated with traffic noise levels ($R= 0.62$, $p<0.0001$), which were associated with a higher risk of myocardial infarction in long-term residents (up to 15 years residence). The link between noise and stress, and elevated odds ratios for most health effects associated with traffic pollution exposure, is well-established throughout the literature (Babisch et al. 2014; Lipfert et al. 2006; Sørensen et al. 2014) To further compound the associations, research has shown that stress increases vulnerability to the physiological impacts of emissions exposure (Clougherty et al. 2006; Shankardass et al. 2009). One such study has also been conducted for the local area that is the focus of this thesis.

In a birth cohort study of 1,398 Pacific Island children, Clougherty et al. (2008) found that maternal acculturation - how well one acclimatises to local culture while maintaining attitudes and beliefs from the nation of origin - slightly enhanced a positive effect of roadway proximity (and NO_2 concentrations) on childhood asthma diagnosis. Domestic violence, another major stressor, was also found to enhance the effect. New Zealand-based traffic-related health effects studies are few in number but there is some literature which suggests minority populations are more susceptible to emissions exposure than the general population. Disproportionate rates of respiratory problems, diabetes, indoor mould and overcrowding are a few examples of issues which can increase susceptibility (Bullen et al. 2008; Cheer et al. 2002).

In summary, any statistically significant associations identified by health effects studies should be viewed with caution and the impacts of noise, stress and enhanced susceptibility, considered as co-contributors. The collective results from the health literature are often inconclusive. More recent studies that report only moderate or weak associations may do so as a result of better control for confounding and misclassification e.g. Andersen et al. 2012; Heck et al. 2013 (see Table 2.2).

Table 2.2 Summary of near-highway health effects studies

Year	Authors	Location (major highways in area, if specified)	Type of health effect targeted	Methods employed	Study Population	Metres from Roadway (proximity subjects reside in)	Pollutant/s investigated or proxy measure used	Duration of study	Main findings
1977	Blumer	Unspecified mountain town, Switzerland	Cancer - mortality	PAH soil testing, study population mortality	3,000 inhabitants	Unspecified (varying)	PAH	12 years	The low values in town close to industry but remote from the highway, and high PAH values outside of town but near the highway suggest a correlation between automobile traffic and PAH content of soils. These results indirectly suggest a correlation between traffic and the observed mortality from cancer.
1998	Feychting et al.	Sweden	Childhood cancer	Estimates of outdoor air concentrations of NO_2 at homes Data from Swedish cancer register Conditional logistic regression	127,000 children, aged 0 - 15 yrs	Unspecified (varying)	NO_2	25 years	The results indicate an association between childhood cancer and motor vehicle exhaust, although the number of cases was small. These findings and the results of previous studies suggest that further studies are warranted.
2000	Pikhart et al.	Prague, Czech Republic	Childhood wheeze	Surveys distributed in schools Modelling of pollutant concentrations Logistic regression	3,680 children, aged 7 - 10 yrs	Unspecified (varying)	NO_2, SO_2	1 year	Many limitations acknowledged, including limited spatial variation of NO_2 across the city and problem of assigning outdoor concentrations to individuals who spend most of their time indoors. Study reported a minor heightened odds ratio (1.16) per 10 $\mu g/m^3$ increase.

2000	Krämer et al.	Düsseldorf, Germany	Childhood atopy	NO_2 field measurements Personal exposure monitoring Questionnaire Clinical testing	844 children living near major roads	< 200	NO_2	2 years	Hay fever, symptoms of allergic rhinitis, wheezing, sensitisation against pollen, house dust mites or cats, and milk or eggs were associated with outdoor NO_2. The results indicate that traffic-related air pollution leads to increased prevalence of atopic sensitisations, allergic symptoms and diseases.
2000	Pearson et al.	Denver, CO, USA	Childhood cancer	Exposure metrics based on traffic volume Colorado Central Cancer Registry	320 children diagnosed with cancers, aged 0 - 14 yrs	Unspecified (varying)	Traffic metrics	6 years	Results were strongest in the highest traffic density category. The odds ratio was 5.90 and 8.28 for leukaemia. The results are suggestive of an association between proximal high traffic streets with traffic counts 20,000 VPD and childhood cancer, including leukaemia.
2003	Maheswaran & Elliott	England & Wales, UK	Stroke - mortality	Distance to main roads Census data Poisson regression	19,083,979 adults, aged ≥ 45 yrs.	< 200 200 - <500 500 - <1000 ≤ 1000	Traffic proximity	2 years	Stroke mortality risk was 7% higher in men living within 200 m of a main road compared with men living 1000 m away. The risk for women was 4%. Combined risk (both sexes) was 5%. Living near main roads is associated with excess risk of mortality from stroke, and if causality were assumed, ~990 stroke deaths per year would have been attributable to road traffic pollution.
2003	Wilhelm & Ritz	Los Angeles, CA, USA	Premature birth	Distance-weighted traffic density measures Birth certificates from California Department of Health Services	30,122 pregnant women	Unspecified (varying)	Traffic proximity	2 years	They observed an approximately 10-20% increase in risk of preterm birth (both normal and low weight) and term LBW in infants born to women potentially exposed to high levels of traffic-related air pollution, as represented by traffic density.

2006	Lipfert et al.	USA	All-cause mortality	Traffic density measures Mortality data	70,000 male war veterans	Unspecified (varying)	NO_2 , O_3, CO, SO_2, $PM_{2.5}$, PM_{10}, SO_4, Traffic metrics	25 years	Modest changes in traffic-related mortality risks fro the period 1976–2001, despite the decline in regulated tailpipe emissions per vehicle since the mid-1970s. Suggests that other environmental effects may be involved, such as particles from brake, tire, and road wear, traffic noise, psychological stress, and spatial gradients in socioeconomic status.
2007	Gauderman et al.	California, CA, USA	Childhood pulmonary development	Clinical testing Regression analysis Traffic metrics Dispersion models Exposure estimates at home address	3,677 children, aged 10 yrs	< 500 500 - 1000 1000 - 1500 > 1500	NO_2	8 years	Children who lived within 500 m of a freeway had substantial deficits in 8-year growth of FEV and maximum mid-expiratory flow rate compared with children who lived at least 1500 m from a freeway. Pronounced deficits in lung function at age 18 years were recorded for those living within 500 m of a freeway,
2007	Finkelstein & Jerrett	Hamilton and Toronto, ON, Canada	Parkinson's disease	Residential proximity to traffic Ministry of Health databases	110,000, adults mostly aged 65 yrs+	< 50 50 - 100	NO_2 Traffic proximity	8 years	Examination of prevalence curves suggested that exposure to ambient Mn (a fuel additive) advances the onset of Parkinson's, consistent with the theory that exposure to Mn adds to the natural loss of neurons attributable to the aging process.
2007	Hoffmann et al.	Essen, Mülheim, and Bochum, Germany	Coronary - atherosclerosis	Residential proximity to traffic German Heinz Nixdorf Recall Study	4,494, adults aged 45 - 74 yrs	< 50 51 - 100 101 - 200 > 200	$PM_{2.5}$ Traffic proximity	3 years	Compared with those living > 200 m away, odds ratios were 1.63, 1.34 and 1.08 for < 50, 51 - 100 and 101 - 200, respectively, for a high coronary artery calcification. Long-term residential exposure to high traffic is associated with the degree of coronary atherosclerosis

2008	Beelen et al.	The Netherlands	All-cause mortality	LUR models using mortality records for a cohort recruited from the Netherlands Cohort Study on Diet and Cancer (NLCS)	120,852	Unspecified (varying)	NO_2, BS, $PM_{2.5}$, SO_2	10 years	Traffic-related air pollution and several traffic exposure variables were associated with mortality in the full cohort. Relative risks were generally small. Associations between natural-cause and respiratory mortality were statistically significant for NO_2 and BS.
2008	Hu et al.	Florida, USA	Stroke - mortality	Traffic metrics Bayesian hierarchical modelling Dasymetric mapping National Vital Statistics System	Not stated	Unspecified (varying)	Traffic metrics Traffic proximity	5 years	High risk of stroke mortality was found in areas with low income levels, high traffic air pollution level, and low level of exposure to green space.
2009	Margolis et al. 2009	Fesno, CA, USA	Childhood pulmonary function	Multiple linear regression between traffic metrics and pulmonary function determined via patient survey and clinical testing	214 asthmatic children, aged 6 - 11 yrs	Varying (citywide)	Proximity to major roads, traffic volumes, traffic composition	2 years	Residence proximity to highway traffic is associated with lower pulmonary function among children with asthma, and smaller airway size is an important modifier of the effect of traffic exposure on pulmonary function and a marker of increased susceptibility.
2009	Baccarelli et al.	Lombardia Region, Italy	Deep vein thrombosis	Thrombophilia Screening visits Logistic regression	1,522, adults aged 18 - 84 yrs	0 - 718	PM_{10} (urban background) Proximity to major roads	10 years	The increase in DVT risk was approximately linear over the observed distance range and was not modified after adjusting for background levels of particulate matter. Living near major traffic roads is associated with increased risk of DVT.

2009	Hart et al.	USA, continental	Rheumatoid arthritis	GIS distance-to-road Nurses' Health Study Cox proportional hazard models	90,297, adult females aged 30 - 55 yrs	< 50 ≥ 50 < 200 ≥ 200	Proximity to major roads	24 years	An elevated risk of RA was observed (HR = 1.31) in women living within 50 m of a road compared with living 200 m or farther. This suggests that pollution from traffic in adulthood may be a newly identified environmental risk factor for RA
2009	Ranft et al.	Ruhr, Germany	Alzheimer's disease	GIS distance-to-road Cognitive testing	399, adult females aged 68 - 79 yrs	≤ 50 > 50 ≤ 100 > 100	NO_2, $PM_{2.5}$, soot in $PM_{2.5}$ Proximity to major roads	23 years	Subjects were assessed for mild cognitive impairment by several neuropsychological tests. Consistent effects of traffic-related air pollution exposure on test performances were found. Indicates that chronic exposure to traffic-related PM may be involved in the pathogenesis of AD.
2010	Tsai et al.	Taichung, Taiwan	Cardiovascular - mortality	Fixed-site ambient monitoring Mortality data	1,217,690 inhabitants	Varying (region-wide)	NO_2, CO, PM_{10}, VOCs	3 years	Single-pollutant models showed that cardiovascular mortality was significantly associated with NO_2, propane, isobutane and benzene. These associations for acute exposure to traffic air pollutants have important implications for the study of cardiovascular mortality in urban environments.
2011	Sørensen et al.	Copenhagen and Aarhus, Denmark	Stroke	Fixed-site ambient monitoring Road traffic noise	57,053 adults, aged 50 - 64 yrs	Varying (citywide)	NO_x Noise levels	14 years	There was a statistically significant interaction with age, with a strong association between road traffic noise and stroke among cases over 64.5 years. However, there was no associated risk for NO_x exposure, suggesting an independent effect of road traffic noise.

2011	Gan et al.	Vancouver, BC, Canada	Cardiovascular - heart disease	LUR models using data for CHD hospitalisations and deaths at provincial hospitals	452,735 adults, 45 - 85 yrs of age	Varying (citywide)	BC, $PM_{2.5}$, NO_2	9 years 5-year exposure period and 4-year follow-up.	Clear linear exposure–response relationships between black carbon and coronary events. Long-term exposure to traffic-related fine particulate air pollution, indicated by BC, may partly explain the observed associations between exposure to road traffic and adverse cardiovascular outcomes.
2011	Hart et al.	USA, continental	All-cause mortality	Occupational exposure modelling GIS spatial smoothing Cox proportional hazard modelling	53,814 adults, mean age of 42 yrs	Varying (nationwide)	NO_2, SO_2, $PM_{2.5}$, PM_{10}	15 years	Long-term exposures to particulate matter less than 10 mm in diameter, particulate matter less than 2.5 mm in diameter, SO_2, and NO_2 are independently associated with mortality, even after control for occupational traffic exposures.
2011	Wilhelm et al.	Los Angeles, CA, USA	Premature birth	Exposure modelling Conditional logistic regression	276,891 pregnant women	Varying (county-wide)	NO_x, NO, NO_2, PM2.5, OC, EC	2.5 years	Odds of preterm birth increased 6-21% per inter-quartile range increase in entire pregnancy exposures to OC, EC, benzene, and diesel, biomass burning and ammonium nitrate PM2.5, and 30% per inter-quartile increase in PAHs
2012	Riley et al.	Hamilton, ON, Canada	Respiratory - airway hyper-responsivenes s	Clinical testing Multivariate regression with proximity to major roads and highways	2,625 asthmatics attending an outpatient clinic, aged 18 - 88 yrs	Varying (citywide)	Proximity to major roads, including 8 close-proximity discrete zones (divided within 0 - 400 m)	3 years	Those who lived within 200 m of a major road had increased odds of having moderate airway hyper-responsiveness compared with having a normal response. The majority of patients with severe airway hyper-responsiveness lived within the urban core of the city.

2012	Rundle et al.	Bronx and Manhatten, NY, USA	Childhood obesity	Personal $PM_{2.5}$ monitoring PAH extraction from filters, gas chromatography Clinical measurements at birth and follow-up clinics	422 African-American and Hispanic infants, aged 0 - 7 yrs	Unspecified	$PM_{2.5}$, PAH	Personal monitoring: 2 days Entire study: 8 years	Compared with children of mothers in the lowest tertile of PAH exposure, children of mothers in the highest exposure tertile had a higher relative risk of 1.79 for obesity at age 5 years, and a relative risk of 2.26 at age 7 years. The data indicate that prenatal exposure to PAHs is associated with obesity in childhood.
2012	Perera et al.	Bronx and Manhatten, NY, USA	Childhood attention deficit, anxiety and depression	Personal $PM_{2.5}$ monitoring PAH extraction from filters, gas chromatography Multivariate analyses	422 African-American and Dominican infants, aged 0 - 7 yrs	Unspecified	$PM_{2.5}$, PAH	Personal monitoring: 2 days Entire study: 8 years	High prenatal PAH exposure, whether characterized by personal air monitoring or maternal and cord adducts (detectable or higher), was positively associated with symptoms of Anxious/Depressed and Attention Problems.
2012	Sørensen et al.	Copenhagen and Aarhus, Denmark	Cardiovascular - heart attack	Fixed-site ambient monitoring Road traffic noise	57,053 adults, aged 50 - 64 yrs	Varying (citywide)	NO_x Noise levels	14 years	Exposure to long-term residential road traffic noise was associated with a higher risk for myocardial infarction in a dose dependent manner.
2012	Andersen et al.	throughout Denmark	Diabetes	LUR models using data from the Danish National Diabetes Register (NDR)	57,053 adults, aged 50 - 64 yrs	Varying (nationwide)	NO_x, NO_2	5 years	Diabetes risk was weakly positively associated with increasing mean levels of traffic-related air pollution at the residence. The risk was highest in non-smokers and physically active people.
2013	Brugge et al.	Boston, MA, USA (I-93, 8 lanes, 150,000/day)	Cardiovascular - heart disease	Pollutant sampling Clinical testing	260 adults > 40 yrs of age	< 450	UFPs (6 - 213 nm)	Pollutant measurements: 55 days throughout 1 year Participant surveying and field clinics: 2 years	Identified associations between highway proximity and cardiovascular disease risk, with non-monotonic patterns explained partly by individual-level factors and differences between proximity and UFP concentrations.

2013	Hystad et al.	Eight provinces throughout Canada	Lung cancer	Ambient monitoring Spatiotemporal exposure modelling at residence Traffic proximity measures	5,897 adults	< 100 m of major highways	NO_2, O_3, $PM_{2.5}$	3 years health data, 20 years residential exposure modelling	Lung cancer incidence was increased most strongly with NO_2 and $PM_{2.5}$ exposure. There was increased risk among those living within 100 m of highways, but not among those living near major roads. Further investigation is needed into possible effects of O_3 on development of lung cancer.
2013	Chiu et al.	Boston, MA, USA	Childhood attention deficit	Estimated BC levels at home address using LUR Conner's Continuous Performance Test	174 Hispanic and Caucasian children, aged 7 - 14 yrs	Varying (citywide)	BC	7 years	Reported associations between BC (a marker of traffic pollution) exposure and higher commission errors and slower reaction time. These associations were overall more apparent in boys than girls.
2013	Volk et al.	California, USA	Autism	Line-source air dispersion modelling Autism Diagnostic Interview	524 infants, aged 24 - 60 months	Varying (state-wide)	NO_2, $PM_{2.5}$, PM_{10}, O_3	4 years	Autistic children were more likely to live at residences that had the highest quartile of exposure to NO_2, $PM_{2.5}$ and PM_{10}, during gestation and during the first year of life, compared with control children.
2013	Heck et al.	California, USA	Childhood cancer	Dispersion modelling Traffic metrics California Cancer Registry	3,590 children aged < 6 yrs	< 300 < 500 < 1000	CO, $PM_{2.5}$	9 years	Weak associations between early exposure to traffic pollution and several childhood cancers. Because this is the first study to report on traffic pollution in relation to these cancer types, the findings require replication in other studies.
2014	Gruzieva et al.	Stockholm, Sweden	Childhood asthma	Emissions databases Dispersion models Time-activity Questionnaires Clinical samples	4086 children, aged 0 - 12 yrs	Varying (citywide)	NO_x, PM_{10}	12 years	Moderate associations between NO_x & PM_{10} exposure during the first year of life and asthma and wheezing in children up to 12 yrs of age. Asthma risks seemed to be particularly increased in children age 8 to 12 yrs.

2.4 Roadside gradients of traffic pollution from busy highways

The distance to which elevated concentrations (above background) from traffic emissions sources extend into residential communities is of primary consideration in quantifying potential exposures. Health effects studies which utilise LUR and traffic proximity normally do not account for diurnal variation of traffic volume and the influence of local meteorology. Where high volume roads are concerned, concentrations of primary traffic pollutants such as NO_x, CO and UFPs do not reach background levels until somewhere around 300 m downwind and can extend as far as 2.5 km during early morning temperature inversions (Hu et al. 2009; Karner et al. 2010; Zhou & Levy 2007). However, for the purposes of exposure assessment, it cannot be assumed that this applies to both sides of a highway as prevailing winds can result in one side of the road being upwind under most conditions. Unless there is no wind flow, concentrations at the upwind side generally represent background levels and can be lower than hundreds of metres downwind (Hagler et al. 2009; Zhu et al. 2006). While stress from noise and general roadway activity remains a factor, potential exposure to emissions can be somewhat limited at the upwind side.

Comparing near-highway studies can be problematic. Different seasons, instrument types, strength of quality assurance and varying averaging times somewhat diminishes comparability. Most studies have used handheld portable instruments or instruments mounted in vehicles, which are shifted between measurement points to collect samples for very brief periods of approximately ten minutes (see Tables 2.3 and 2.5). A study using ten minute sampling periods found CO levels declined by 80%, 300 m downwind (Zhu et al. 2004) yet another with a one year monitoring period only reported a reduction of only 25% at the same distance (Kimbrough et al. 2013). For short measurement periods, sampling is normally done during the day when traffic volumes are highest. These peak concentrations seen during rush hour rapidly drop with distance from road due to dispersion from local winds, resulting in the sharpest decay gradients possible, which can inadequately represent the long-term situation. Of the 15 studies summarised in Tables 2.3 - 2.6 (for UFPs, NO_x, CO & PM_{10}), only three employed continuous, simultaneous monitoring for a period of more than one day (Birmili et al. 2009; Kimbrough et al. 2013; Roorda-Knape et al. 1998). The extremely mixed results (no obvious gradient away from roads) reported by Fuller et al. (2013, see Table 2.3) highlight the difficulty of non-concurrent sampling at different time periods.

Variation in size mode measurement of different ultrafine particle counters provides a good example of inter-comparability issues. By definition, ultrafine particles are particles that have an aerodynamic diameter of < 100 nm. Technically, if the size range exceeds 100 nm then the measurements should be reported as particle number counts (PNC). Handheld instruments such as the TSI P-Trak and 3007 are said to under-predict total ultrafine particle concentrations as they only detect particles down to 10 - 20 nm (Zhu et al. 2006), but they also measure particles up to 1 μm; larger CPCs generally have a cut off of around 500 nm. However, a later study found concentrations measured by P-Trak instruments were better correlated (*R*= 0.7 - 0.9) with the lower size regions (10 - 100 nm) measured by an SMPS than for > 100 nm (*R*= 0.3 - 0.5), indicating that P-Traks represent the general trend of freshly generated roadside UFP concentrations (Hagler et al. 2009). As such, it is accepted across the literature to refer to counts measured by such instruments as UFPs. The larger the particle size mode, the wider the spatial extent, so a degree of caution is still required when comparing results. Zhu et al. (2004) demonstrated that particles in the 6 - 50 nm mode are almost entirely lost by 300 m downwind (96 - 98% decay during summer) and the percentage reduction starts to decline for the larger size modes (86 - 88% for 50 - 200 nm, see Table 2.3). This is reduced even further as particle sizes increase, as smaller particles are rapidly lost due to coagulation and condensation processes. Hence we may expect to see weaker gradients where the >500 nm size modes are included e.g. Hitchins et al. 2000.

In summary, the spatial extent of near-roadway emissions is highly variable and results from one area are not necessarily transferable to another without accounting for local meteorology and traffic differences. The instruments used, averaging periods and total monitoring timeframe should also be considered. Currently, there is a clear lack of research reporting long-term deployments of concurrent near-highway monitors as well as an overall lack of CO and NO_x deployments, with UFPs being the primary focus (Tables 2.3 - 2.5).

Table 2.3 Summary of studies investigating near-highway decay - UFPs

Year	Author/s	Location (highway/s)	Approximate mean traffic volume (lanes)	Instrument/s	Sampling duration & season (simultaneous sampling at sites?)	Metres from roadway (measured from)	Upwind or down	Approximate total particle number mean concentration in pt/cm^3 (size range)	Percentage reduction from measurem ent point nearest roadway
2000	Hitchins et	Tingalpa, QLD,	3,400/hr (4)	TSI SMPS 3934	15 min, not	15 (roadway edge)	Down	83,000 (5 - 900 nm)	-
	al.	Australia		APS 3310A	stated (no)	55		69,000	17
		(Gateway				215		19,000	77
		motorway &				295		8,000	90
		Wynnum Rd)				375		20,000	76
			2,130/hr (4)		15 min, not	15 (roadway edge)	Down	34,000	-
					stated (no)	40		26,000	24
						80		25,000	26
						120		17,000	50
						160		14,000	59
						200		24,000	29
						240		17,000	50
						280		23,000	32
2002a	Zhu et al.	Los Angeles, CA,	13,900/hr (9)	TSI SMPS 3936	9 min, spring,	30 (centre of median strip)	Down	150,000 (6 - 220 nm)	-
		USA (I-405)		TSI CPC 3022A	summer (no)	60		88,000	41
						90		70,000	53
						150		50,000	66
						300		37,000	75
2002b	Zhu et al.	Los Angeles, CA,	12,180/hr (8)	TSI SMPS 3936	9 min, summer,	17 (centre of median strip)	Down	200,000 (6 - 220 nm)	-
		USA (I-710)		TSI CPC 3022A	autumn (no)	20		180,000	10
						30		160,000	20
						90		72,000	64
						150		61,000	70
						300		49,000	76
						200	Up	48,000	76

2003	Reponen et al.	Cincinnati, OH, USA (I-75, I-71)	140,000/day (6)	TSI P-Trak 8525	10 min, not stated (no)	50 (roadway edge)	Down	174,000 (20 nm - 1 μm)	-
						150		114,000	34
						200		71,000	59
						400		34,000	80
						800		7,000	96
						1600		17,000	90
			140,000/day (6)		10 min, not stated (no)	50 (roadway edge)	Down	71,000	-
						150		44,000	38
						200		18,000	75
						400		18,000	75
						800		13,000	82
						1600		12,000	83
2004	Zhu et al.	Los Angeles, CA, USA (I-405)	12,300/hr (9)	TSI SMPS 3936 TSI CPC 3022A	10 min, winter (no)	30 (centre of median strip)	Down	41,000 (6 - 12 nm)	-
						60		27,000	34
						90		19,000	54
						150		12,000	71
						300		8,000	80
					10 min, summer (no)	30 (centre of median strip)	Down	20,000 (6 -12 nm)	-
						60		5,000	75
						90		2,000	90
						150		1,000	95
						300		500	98
					10 min, winter (no)	30 (centre of median strip)	Down	19,000 (12 - 25 nm)	-
						60		17,500	8
						90		9,500	50
						150		8,500	55
						300		6,000	68
					10 min, summer (no)	30 (centre of median strip)	Down	26,500 (12 -25 nm)	-
						60		13,000	51
						90		7,000	74
						150		2,000	92
						300		1,000	96
					10 min, winter (no)	30 (centre of median strip)	Down	8,500 (25 - 50 nm)	-
						60		9,000	6
						90		4,500	47
						150		4,000	53

						300		3000	65
					10 min, summer (no)	30 (centre of median strip)	Down	25,500 (25 - 50 nm)	-
						60		23,500	8
						90		12,500	51
						150		4,500	82
						300		1,000	96
					10 min, winter (no)	30 (centre of median strip)	Down	3,800 (50 - 100 nm)	-
						60		2,500	34
						90		2,000	47
						150		1,600	58
						300		1,200	68
					10 min, summer (no)	30 (centre of median strip)	Down	10,000 (50 - 100 nm)	-
						60		6,900	31
						90		5,200	48
						150		3,300	67
						300		1,200	88
					10 min, winter (no)	30 (centre of median strip)	Down	940 (100 - 200 nm)	-
						60		750	20
						90		640	32
						150		480	49
						300		320	66
					10 min, summer (no)	30 (centre of median strip)	Down	2150 (100 - 200 nm)	-
						60		850	60
						90		1280	40
						150		620	71
						300		300	86
2006	Zhu et al.	Los Angeles, CA, USA (I-405)	1,200 - 4,200/hr (9)	TSI SMPS 3936 TSI CPC 3022A	6 min, 5 hrs total over 7 nights during winter (no)	30 (centre of median strip)	Down	118,000 (7 - 300 nm)	-
						60		96,000	19
						90		80,000	32
						150		64,000	46
						300		54,000	54
						500		52,000	56
						30 (centre of median strip)	Up	16,000	-
						60		14,000	13
						90		17,000	6
						150		9,000	44

						300		8,000	50
2009	Birmili et al.	Berlin, Germany, (A100)	147,500/day (6)	TDSMPS TSI SMPS 3080 TSI CPC 3010	36 - 68 days, summer, autumn (yes, mostly)	4 (roadway edge) 80 400	Up Down Down	28,000 (10 - 500 nm) 11,000 9,000	- 61 68
2009	Hagler et al.	Raleigh, NC, USA (I-440)	125,000/day (8)	TSI P-Trak 8525	1.5 hrs over 7 days, summer (yes)	20 (roadway edge) 50 100 300 50	Down Up	27,000 (20 - 1 µm) 20,000 15,000 10,000 8,000	- 26 44 63 70
2013	Fuller et al.	Somerville, MA, USA (I-93)	150,000/day (8)	TSI CPC 3781	7 - 21 days over 172 days, spring, summer, autumn (no)	33 (roadway edge) 68 101 304 85 (roadway edge) 94 118 123 138 152 197 206 221 289 402 1408 1424 1483	Down Up	*7,400 (6 - 3000 nm)* *7,800 [median values]* *4,500* *5,300* *5,100* *8,600* *6,200* *3,900* *5,500* *6,000* *6,600* *6,100* *8,100* *6,000* *4,600* *6,300* *3,600* *3,200*	- +5 39 28 - +69 +22 24 +8 +18 +29 +20 +59 +18 10 +24 29 37
2014	Shu et al.	Los Angeles, CA, USA (I-405)	10,200/hr (9)	TSI CPC 3007	5 min, 20 times, over 9 days (yes)	45 (roadway edge) 75 105 165 285 45 (roadway edge) 75 105 165	Down Up	27,000 (10 nm - 1 µm) 14,000 13,000 12,500 10,500 10,500 9,500 10,200 10,600	- 48 52 54 61 - 10 3 +1

						285		10,000	5

Table 2.4 Summary of studies investigating near-highway decay - NO_x

Year	Authors	Location (highway/s)	Mean traffic volume (lanes)	Instrument/s	Sampling duration & season (simultaneous sampling at sites?)	Metres from roadway (measured from)	Upwind or down	Mean concentration (units)	Percentage reduction from measurement point nearest roadway
2003	Gilbert et al.	Montreal, QC, Canada (A-15)	185,000 (8)	Ogawa passive samplers (NO_2)	7 days (yes)	0 (above highway centre) 100 170 250 520 900 1310 0 (above highway centre) 160 230 500 800	Down Up	29 (ppb, NO_2) 23 20 17 15 15 14 29 (ppb, NO_2) 18 15 13 11	- 21 31 41 48 48 52 - 38 48 55 62
2013	Kimbrough et al.	Las Vegas, NV (I-15)	206,000/day (12)	EC 9841B	One year (yes)	20 (roadway edge) 100 300 100	Down Up	56 (ppb) 41 35 25 (ppb)	- 27 38 -

Table 2.5 Summary of studies investigating near-highway decay - CO

Year	Authors	Location (highway/s)	Mean traffic volume (lanes)	Instrument/s	Sampling duration & season (simultaneous sampling at sites?)	Metres from roadway (measured from)	Upwind or down	Mean concentration (units)	Percentage reduction from measurement point nearest roadway
2004	Zhu et al.	Los Angeles, CA, USA (I-710)	13,800/hr (8)	Dasibi Model 3008	10 min, winter (no)	30 (centre of median strip) 60 90 150 300	Down	2.1 (ppm) 1.3 1.0 0.8 0.5	- 38 52 62 76
					10 min, summer (no)	30 (centre of median strip) 60 90 150 300	Down	2.0 (ppm) 0.9 0.6 0.5 0.4	- 55 70 75 80
2013	Kimbrough et al.	Las Vegas, NV, USA (I-15)	206,000/day (12)	EC 9830 T Serinus 30	One year (yes)	20 (roadway edge) 100 300	Down	0.40 (ppm) 0.32 0.30	- 20 25
						100	Up	0.25 (ppm)	-

Table 2.6 Summary of studies investigating near-highway decay - PM_{10}

Year	Authors	Location (highway/s)	Instrument/s	Mean traffic volume (lanes)	Sampling duration & season (simultaneous sampling at sites?)	Metres from roadway (measured from)	Upwind or down	Mean concentration ($\mu g/m^3$)	Percentage reduction from measurement point nearest roadway
1998	Roorda-Knape et al.	Delft , The Netherlands (A13)	Andersen teflon filters (PM mass)	119,376/day (8)	2 weeks each time, over 6 weeks, spring/summer (yes)	15 115 165 305	Down	32.2 30.2 28.9 30.6	- 6.2 10.2 5.0
		Overschie (A13)		119,966/day (8)		32 82 133 260	Down	32.1 33.1 30.8 32.3	- +3.1 4.0 +0.6

2.5 Environmental justice

Environmental justice is defined as maintaining fairly spatially distributed environmental burdens and benefits across all socioeconomic and racial groups, from the local scale to worldwide equity between developed and developing countries. The term stems from the 1980s environmental racism movement in the United States, when minority groups fought against increasing unjust placements of landfills and hazardous polluting factories (Cole & Foster 2001). The bulk of environmental justice studies conducted in the US, Canada and Europe, compare exposure and/or health outcomes in higher socioeconomic zones with those situated alongside freeways and near industrial zones, where lower land values are expected. The US literature tends to conclude that African-Americans and Hispanics are exposed to higher levels of traffic emissions (and air toxics in general) than European-Americans (Bae et al. 2007; Marshall 2008; Morello-Frosch & Jesdale 2006; Stuart et al. 2009). However, differences in historical stratification of cities mean that the situation in other countries can be in stark contrast. A recent study in Rome found that the middle-class and the elderly were the highest exposed to traffic fumes as they were more likely to live near the railway ring and the historical centre (Cesaroni et al. 2010). For Hamilton, Canada, a study found Latin-Americans were positively associated with exposure, Asian-Canadians negatively associated and no correlation was established for African-Canadians. The authors suggested that these “dimensions of environmental racism” were “driven by economic status at time of entry [arrival to city]” (Buzelli & Jerrett 2004, p. 1855). In the megacity of São Paulo, Brazil, the nature in which the city developed has seen the most heavily trafficked downtown areas (with the best city access) remain the most desirable and most expensive places to live compared to the periphery; the situation is similar for Manhattan, New York (Clougherty et al. 2013; Habermann et al. 2014). These findings highlight the extent to which disproportionate city exposure can differ between cities and countries. While socioeconomic or racial environmental injustice may be perceived to exist among certain populations, city-wide investigation is required and results can be counter-intuitive.

Table 2.7 summarises the bulk of the standout environmental justice studies completed, starting with Morello-Frosch et al. (2001) - a landmark paper that is one of the most widely cited in environmental inequity research today. The authors estimated that mobile-source (transport) pollutants account for 70% of cancer cases associated with ambient air pollution throughout the state of California, with African-Americans and Latinos facing the highest risk ratios. Since then, numerous studies have confirmed a greater exposure risk at place of residence for minority populations throughout large parts of California (Houston et al. 2004; Lee et al. 2009; Marshall et al.

2008; Marshall et al. 2014; Ponce et al. 2005). Houston et al. (2004), in an analysis of urban traffic disparities throughout Southern California, found minority and high-poverty neighbourhoods were exposed to traffic densities two-fold greater than in higher income areas. The authors explain that this is due to a mixture of historical racial segregation, persisting discrimination within the housing market and fragmented land-use zoning, allowing for uneven development. These minority neighbourhoods also have a large proportion of multi-family homes (32 - 48%) and over 40% of the residential buildings are pre-1960s. Increased foot traffic in older homes, which typically lack proper insulation from the outdoor environment, results in more rapid Air Exchange Rates (AERs), elevating penetration of outdoor air.

Further north, Bae et al. (2007) performed a census analysis of the entire population living within 100 m of all major freeways (AADT ≥ 100,000) in the Seattle/Portland regions. They found that the total population (number) of low-income residents was 1.36 times higher in the immediate freeway corridors than anywhere else; this figure for African-Americans was a factor of 2 - 3 higher. The authors recommended re-zoning these freeway pollution airsheds for commercial and industrial use, or at least shifting sensitive facilities such as senior-citizen and daycare centres, out of this zone of influence. They also call for regulatory monitoring in these areas - a call which has since been extended to the entire country, with a nationwide analysis showing 85 - 93% (varying by pollutant type) of the 6.2 million people living within this 100 m zone have no co-located air quality monitor (Rowangould 2013). Extended to within 500 m, up to 27.5 million have no regulatory monitoring. As a first step, putting adequate monitoring in place is preferable to mitigation options, which can be incredibly difficult to implement due to the existing built environment and political barriers within local planning. It is plausible that a sizable percentage of those 27.5 million without monitoring do not have issues with long-term elevated concentrations due to local characteristics such as being situated predominately upwind or having adequate dispersion during high-traffic hours.

Environmental justice research of any type is very limited in the Australasian region. Only two have been completed for traffic-related emissions in New Zealand and it appears that none exist for Australia. Kingham et al. (2007) conducted a study for the city of Christchurch (population ~360,000) where vehicle kilometres travelled (VKT) were used to estimate the contribution of traffic to annual modelled PM_{10} concentrations for each census area unit (CAU). Results suggested that potential mean exposure to traffic-emitted PM_{10} is highest in the most socioeconomically deprived areas of the city. The same methods were later extended to a nationwide analysis, which reported an even distribution of exposures across income levels (Pearce & Kingham 2008). For several reasons, these studies poorly represent variation in traffic emissions exposure. Traffic emissions generally contribute a minor portion towards total PM_{10} concentration, which is predominantly made up of natural background (fine soils, suspended dust, sea spray), domestic heating and industrial sources (Senaratne & Shooter 2004; Wilton et al. 2010). Due to the larger size and non-reactive nature of these particles, local-scale spatial variation is typically limited and concentrations can be well-correlated many kilometres apart (Pakbin et al. 2010). Near-highway monitoring in two Dutch cities also found that there was no variation in concentrations measured at multiple distances downwind (up to 300 m) of major highways (AADT > 100,000), at distances where there would be extreme variation in levels of primary traffic pollutants (Roorda-Knape et al. 1998, Table 2.6). Furthermore, the New Zealand studies used CAUs (and neighbouring CAUs), which can be as large as 10 km^2 in the main urban centres, to assign exposures to residents. While this is suitable for PM_{10} in general, it does not adequately represent spatial variation for the bulk of air toxics emitted from exhaust pipes. The PM_{10} portion calculated as originating from vehicles only represents the combined contribution of all roads (within a large spatial unit) to the general urban background - which is expected to be reasonably spatially uniform across wide urban areas, in which people of all income levels reside. Therefore, comparing traffic-contributed PM_{10} with measures of income at this crude scale is likely to substantially underestimate spatial contrasts in the extent of traffic emissions impacts; in other words, to underestimate the risks to residents closest to busy roads while overstating the risks to those who live in urban background locations. Of the 17 studies presented in Table 2.7, only two others are limited to particulate matter measurements, with most preferring to utilise NO_x, NO_2 or CO. The Auckland area would benefit from an analysis similar to that of Bae et al. (2007), where census units adjacent to major roadways were assessed by income and ethnicity. New Zealand census data also consists of finer-scale census units (average size approx. 50,000 m^2), known as 'meshblocks', which are better suited for illustrating potential exposure inequities to spatially heterogenous pollutants with shorter atmospheric residencies.

In summary, the main findings throughout the international literature suggest low socioeconomic and minority groups are disproportionately exposed in many urban areas, but the reverse holds for cities where the most expensive real estate is home to extreme inner-city traffic volumes (Table 2.7). However, these studies only account for potential exposure at place of residence. The most recent work, conducted in Flanders, Belgium, showed that even where environmental injustice exists for the poor, once pollutant dose (total inhaled concentrations) is factored in, the exposure burden is evenly spread (Dons et al. 2014). This study found that, after accounting for exposures while commuting, inhaled dose ended up being similar across income levels since wealthier people travel more, and are more likely to do so during peak hours when emissions are strongest. In cities characterised by urban sprawl, poorer people tend to work at locations near their homes, while the middle to upper-middle class live in upscale urban areas in the city outskirts, resulting in substantially longer commute times. Although the wealthiest may have the shortest commute times, the most desirable central suburbs can also be the most polluted, as reported for New York and São Paulo (Clougherty et al. 2013; Habermann et al. 2014).

Future research should aim to improve exposure classification in the interests of fairly representing environmental justice concerns. This can be achieved by spatially refining concentration estimates (smaller census units, near-field dispersion modelling), validating estimates with denser monitoring regimes (spatial saturation), and incorporating aspects of in-traffic and personal exposure modelling.

Table 2.7 Summary of studies assessing environmental justice for traffic pollutant exposure

Year	Authors	Location (major highways in area, if specified)	Methods employed	Study Population	Metres from Roadway (proximity subjects reside in)	Pollutant/s investigated or proxy measure used	Duration of study	Main findings
2001	Morello-Frosch et al.	South Coast Air Basin, CA, USA	Modelling of outdoor concentrations Census tract data Population Risk Index Multivariate regression	14.6 million	Varying (region-wide)	PM, VOCs	1 year	Mobile source (transport) pollutants account for 70% of cancer cases associated with ambient air pollution. Estimated cancer risks for African-Americans and Latinos exceed the average PRI for all groups in the region, with Latinos experiencing the highest risk levels, even after adjusting for income.
2004	Houston et al.	Southern California	Census tract data Traffic metrics Dissimilarity Index GIS	16 million	Varying (region-wide)	Proximity to roadways Vehicle km travelled model	N/A	Minority and high-poverty neighbourhoods bear over two times the level of traffic density compared to the rest of Southern California, which increases traffic emissions exposure risks. These areas also have older and more multifamily housing, which is associated with higher rates of indoor exposure to outdoor pollutants, including the intrusion of motor vehicle exhaust.
2005	Jacobson et al.	New York City, NY, USA	Proximity to highways	7.3 million	< 200 < 400 < 800	Proximity to highways	N/A	A higher proportion of Hispanic and Asian live within all three distance measures. Caucasians, then African-Americans, are less likely to live in close proximity. Residents in the top third of the income distribution are closer by 28 m than residents in the bottom third, on average.
2005	Ponce et al.	Los Angeles, CA, USA	Ambient measurements Distance-weighted traffic density Preterm birth records Census data	37,347 mothers giving birth	Not specified	NO_2, PM_{10}, CO, O_3,	3 years	Traffic-related air pollution exposure disproportionately affected low SES neighbourhoods in the winter. In these poorer neighbourhoods, the winter season evidenced increased susceptibility among women with known risk factors.

2007	Kingham et al.	Christchurch, New Zealand	Traffic-emitted particulate data Dispersion modelling	330,000	Varying (citywide)	TPM_{10}	1 year	Findings suggest that mean exposure to pollution is highest in the most disadvantaged areas of the city. Areas with high car ownership have relatively low levels of pollution exposure. This is suggestive of social injustices.
2007	Bae et al.	Seattle (I-5, I-405, I-90) Portland (I-5, I-84, I-205, I-405) WA, USA	Census tract data Traffic metrics GIS	Not stated	< 100 m	Spatial analysis of demographics of population living within 100 m of all freeways	N/A	African-Americans and poor low-income groups are disproportionately represented in the freeway corridors. The total population of poor living in these areas is up to 1.36 times greater than elsewhere and 2 - 3 times greater for African-Americans.
2007	Buzzelli & Jerrett	Toronto, ON, Canada (H-401)	Ambient monitoring Census data LUR	5 million	Varying (citywide)	NO_2	2 weeks NO_2 monitori ng	Low-income neighbourhoods were more likely to have higher exposure yet minorities were sometimes negatively associated with exposure. Some high income groups were also susceptible to high exposures. In general, regulatory monitoring was sparse and needs to be expanded to reflect the heterogeneity of NO_2.
2008	Marshall	South Coast Air Basin, CA, USA	Ambient monitoring Linear regression	25,064	Not specified	DPM, benzene, butadiene, chromium, O_3	N/A	For primary traffic pollutants, exposures are above average for people who are non-Caucasian, are from lower-income households, and live in areas with high population density. For ozone (a secondary pollutant), the reverse holds. Disparities ranged between 16 - 40% higher exposure for minority populations above American-Caucasian.
2009	Lee et al.	Los Angeles, CA, USA (I-710)	Emissions modelling Dispersion modelling Microscopic traffic simulation model	San Pedro Bay residents (pop. not stated)	Not specified	CO, NO_x, PM, HC	1 year	Emission modelling, and modelling of the spatial dispersion of pollutants in the corridor can facilitate estimation of health and environmental justice impacts of freight corridor operations. Fleet replacement with cleaner (zero-emission) trucks yielded the most emission reductions. Implementing the proposed modelling framework is feasible and practical.

2009	Stuart et al.	Hillsborough County, FL, USA (I-4, I-275)	Interpolation of monitoring data Proximity to highways LUR Personal monitoring Time activity surveying	998,948	Varying (countywide)	CO, NO_x, SO_2, $PM_{2.5}$, PM_{10}	N/A	African-Americans, Hispanics and those in poverty are disproportionately living closer to traffic emissions and further from regulatory air quality monitoring sites. Small-scale spatial patterns of air pollution are not well characterised in most health effects assessments. Monitoring networks are also typically not dense enough to capture neighbourhood-scale variations in pollution. Better understandings are needed of the potential effects of small-scale pollution patterns on exposures for different groups.
2009	Havard et al.	Strasbourg, France	Dispersion modelling Census data Regression models Spatial autocorrelation	450,000	Not specified	NO_2	1 year	The association between the deprivation index and NO_2 levels was positive and nonlinear with both regression models; the midlevel deprivation areas were the most exposed. Ignoring the spatial autocorrelation in these factors may produce biased and uncertain estimates and lead to erroneous conclusions.
2012	Jephcote & Chen	Leicester, UK	Emissions inventory Spatial interpolation Respiratory hospital admissions Carstairs Index (deprivation) Geographically Weighted Regression	24,556 children, aged 0 - 15 yrs	Varying (citywide)	TPM_{10}	9 years	Significant relationships exist between children's hospitalisation rates and socio-economic status, ethnic minorities, and PM_{10} road-transport emissions. The spatial analyses identified important localised variations, specifically relating to a double-burden of residentially experienced road transport emissions and deprivation affecting inner-city children's respiratory health. Affluent intra-urban communities contribute the highest levels of emission from private transport, while residentially experiencing relatively low exposure.
2013	Rowangould	USA	Roadway metrics US census data Linear regression GIS	USA, continental	< 100 200 - 300 400 - 500	Traffic proximity CO, NO_x, PM_{10}, $PM_{2.5}$ (availability	N/A	19% of the population lives near high volume roads. Greater traffic volume is associated with larger shares of minority groups and lower household incomes, yet there are wide variations

						of monitors only)		in the severity of environmental justice concerns. 84% of all counties show some level of disparity. Most counties with residents living near high volume roads do not have a co-located regulatory monitor.
2013	Tian et al.	USA	Roadway metrics US census data GIS ANOVA	USA, continental	< 100 < 150 < 300 < 500	Traffic proximity	N/A	Compared with low-traffic density tracts, tracts with high traffic densities had percentages of African-American and Hispanics that were more than twice as high, 20% greater poverty levels, and one-third fewer Caucasian residents. Census tracts that had mid-level values for road and traffic densities had the most affluent characteristics. Results suggest that racial/ethnic and socioeconomic disparities exist on national level with respect to lower-income and minority populations living near high traffic and road density areas.
2014	Marshall et al.	Southern California, CA, USA	Dispersion modelling Time-activity surveys Personal exposure modelling Atkinson Index	Not stated	Varying (area-wide)	DPM	1 year	Reducing on-road emissions would improve environmental equality and justice. When prioritising emission reductions based on the four environmental goals, strategies should focus on on-road mobile sources if reducing one source's emissions by a relative amount (e.g., 10%).
2014	Krieger et al.	Boston, MA, USA	US census data Annual average exposure Multivariate linear regression	1,757 adults, aged 25 - 64	Varying (citywide)	BC	1 year	Controlling for age, study, and exam date, the estimated average annual BC exposure for the year prior to study enrolment at the participants' residential address was directly associated with census tract poverty but not with annual household income or education; null associations with race/ethnicity became significant only after controlling for socioeconomic position.
2014	Habermann et al.	São Paulo, SP, Brazil	Traffic density Census data	11.5 million	Varying (citywide)	Traffic density Traffic proximity	N/A	Exposure increased with increasing socioeconomic status. The population with the highest socioeconomic status lives in the most polluted areas of the city. However, place of

								residence alone is not capable of measuring exposure. The study suggests that future epidemiological studies include other indicators of vulnerability.
2014	Carrier et al.	Montreal, QC, Canada	Pollutant sampling Traffic metrics Estimation of exposure at schools	Children, aged 5 - 12 years at 319 schools within a city population of 1.9 million	Varying (citywide)	NO_2 Proximity to highways	N/A	NO_2 concentrations near elementary schools are positively and significantly associated with levels of deprivation at these schools. This study highlights an issue of environmental equity, in showing that students from socioeconomically disadvantaged backgrounds tend to attend elementary schools located in more polluted environments.
2014	Gurram et al.	Hillsborough County, FL, USA	Dispersion modelling Time-activity surveying Travel activity modelling	1,582 adults	Varying (county-wide)	NO_x	1 day	Highest mean exposure concentrations were found for African-Americans (20 μg/m^3), below poverty (18 μg/m^3), and urban residence location (22 μg/m^3). Time in non-residential activities, including travel, was associated with an increase of 0.2 μg/m^3 per hour.
2014	Dons et al.	Flanders, Belgium	Ambient concentrations LUR In-traffic personal exposure models Indoor air models	7 million	Varying (region-wide)	BC Roadway metrics	2 years	People from a lower socioeconomic class were found to be exposed to higher concentrations at home, but 'richer' people travel more, especially in traffic peak ours. This results in an average exposure that is higher for members of lower socioeconomic groups, but inhaled doses are similar in both groups. This analysis suggests that differences in health impact between the groups are almost completely explainable by increased susceptibility to air pollution health effects, and not by increased air pollutant intake.

2.6 Neighbourhood variation of traffic pollutant concentrations

City air pollution monitoring is typically limited to a few sites placed in urban background areas to represent concentrations where most inhabitants live. These sites are normally managed by local authorities for the purposes of ensuring national regulatory and World Health Organization (WHO) concentration limits are not breached. While spatial modelling can help improve the usefulness of these data for a wider population, there are still a number of limitations to using spatially interpolated or modelled results over actual measurements. The accuracy of values is limited by the quality of input data which is often generated by a complex mixture of monitored (pollutant, traffic , meteorological) and predicted data from other models (vehicle kilometres travelled, emissions estimates, dispersion models, land use, etc.). Applying these techniques requires dealing with issues of varying temporality between the datasets, which usually results in estimates of long-term (annual) mean pollutant values (see Table 2.7). Ordinarily, these methods do not capture the short-term influences of meteorology, diverging traffic volumes, diurnal and seasonal variation, or possible benefits from recent mitigation efforts i.e. bus lanes, noise walls, green belts. For high exposure areas where there may be a danger of exceeding regulatory limits, modelled values are insufficient substitutes for data collected by approved monitoring methods.

In recent years, there have been calls to better protect populations near busy traffic sources by increasing monitoring throughout near-highway communities (Padró-Martínez et al. 2012; Rowangould 2013; Zhu et al. 2008). While it is too costly and impractical to have a regulatory monitor on every residential block, it is important that neighbourhood air quality is not misrepresented by a single monitor placed in a low exposure area. Numerous research teams have sought to gain insights into local-scale (intra-suburban), neighbourhood variation by deploying a dense network of monitors or mapping spatial variation using mobile monitoring platforms, with some focusing on high-volume road areas (Tables 2.8 & 2.9). Due to the cost and practical difficulties involved with running multiple continuous monitors, fixed-site spatial saturation networks normally consist of low-cost, passive samplers which measure NO_2 or VOCs (Al Madhoun et al. 2011; Barros et al. 2013; Zhu et al. 2008). These samplers only provide average concentrations (usually days, weeks or months) and come with a certain degree of inaccuracy. Although diurnal variation is lost, they give an excellent indication of spatial variation over longer timeframes. In Camden, NJ, USA, Zhu et al. (2008) used a network of 38 VOC passive samplers to monitor variation across a small area (~2.5 km^2) featuring a six-lane highway and a number of industrial sources including metal processing and recycling yards. The study reported extreme spatial variation in BTEX and MTBE with relative standard deviations (%RSD) as high as 176%, reflecting an inverse distance relationship away from a heavy point source (recycling plant) and mobile sources at the highway. Comparisons with two fixed-site monitors in the area found each would under or over-estimate concentrations recorded by the passive monitors across the area by 10 - 50%. These findings clearly highlight the inadequacies of using a fixed monitor to assign exposures for an entire neighbourhood, suburb or city.

Fixed-site spatial saturation has also been conducted for much wider urban areas. Clougherty et al. (2013) deployed a network of 155 integrated samplers (NO_x, BC, SO_2, $PM_{2.5}$) throughout an approximate 130 km^2 area of New York City, for two weeks during each of the four seasons. They found that traffic density account for 67% of NO_2 variation and that the combined influence of several urban sources accounted for 65 - 84% of the other pollutants measured and concluded that the spatial saturation monitoring is important for identifying long-term exposure disparities.

Fixed-site spatial saturation sampling, even in small areas, can miss much of the steep decay known to occur away from heavy traffic sources (Tables 2.3 - 2.5) as monitors are normally somewhat evenly dispersed across the study area rather than set up to capture potential gradients. These spatial gaps can be filled by using mobile monitoring platforms.

Over the past 15 years, at least 14 studies have employed mobile monitoring to map traffic pollutants over a specific route with the aim of achieving some degree of spatial saturation (Table 2.9). One major advantage over fixed-site monitoring is the ability to gather data at fine spatial and temporal resolutions. The bulk of mobile studies have used industry-standard fast response instruments (1 second logging resolution) housed inside vehicles with time-synchronised GPS tracking. These instruments, which perform well when co-located with regulatory monitors (Federal Equivalent Method), are able to provide relatively accurate (limited by GPS error) mapping of street-to-street concentration fluctuation every few metres, depending on the speed of the vehicle. Another advantage is that, due to only needing one set of instruments, a far wider suite of pollutants can be monitored than for a fixed-site campaign. The key limitations of this type of sampling are threefold; it is more difficult to represent long-term averages without numerous repeated measures across an extended monitoring period; monitoring at the street may not accurately represent exposures at residential locations several metres away; and, removing the immediate influence of exhaust emissions directly in front of the vehicle (contact with excessive peaks), or even the sampling vehicle's own emissions, is inherently difficult to do. Some studies have used electric vehicles, but this still requires mitigating the influence of other road users, such as pulling over when behind a high-emitting vehicle (Hu et al. 2012; Kozawa et al. 2009; Kozawa et al. 2012). Since cyclists have been shown to receive lower exposures than drivers and are able to avoid sitting behind queued traffic at intersections, mounting sampling instrumentation to a bike can help to alleviate direct-contact limitations (Dons et al. 2012; Kingham et al. 2013). Although one study in Antwerp, Belgium, has used a bicycle for spatial mapping, it did not focus on spatial variation away from a major highway like most past mobile monitoring has (Peters et al. 2013).

The main criticism of mobile sampling to date is that most have used arbitrary routes sampled at random times of day, once or twice per day, for no longer than one week (Ash 2008; Baldauf et al. 2008; Durant et al. 2010; Kolb et al. 2004). This type of sampling only provides a brief snapshot of air quality variation under the conditions present at that particular time - more recent monitoring is starting to address this limitation. A 2012 study by Padró-Martínez et al. monitored throughout a 2.3 km^2 residential area bisected by an 8-lane highway (AADT 150,000) in Somerville, MA, USA, for six hours per day (six route repeats) over 55 days throughout one year. They reported extreme spatial variation in PNC, BC, CO and NO, with concentrations around two-fold higher within 50 m of the highway compared to further back. Diurnal, between-day and between-season temporal variations were of similar magnitude to spatial variations. Mobile sampling was also used to measure variation away from a highway in Los Angeles, CA, USA, where the spatial coverage of highway-source UFPs was found to extend to 2.6 km during pre-sunrise hours - over twice the distance measured by any previous study (Hu et al. 2009). Near impossible to capture using traditional fixed measurements, it is these types of community-level understandings that can help improve exposure assessments.

In summary, fixed-site monitoring near highways is very sparse and this is not ideal due to the likelihood of local monitors further back to underestimate concentrations within the roadway corridor. With enough repeated measurement runs across a variety of local conditions (weather, traffic), mobile monitoring can help identify locations better suited to represent long-term exposures with fixed-site installations. Diurnal spatial patterns may also be useful for informing local communities of optimal times to carry out certain activities.

Table 2.8 Summary of spatial saturation studies (or partial saturation) featuring major highways - fixed-site measurements

Year	Authors	Location (major highways in area)	Mean traffic volume (lanes)	Pollutant/s measured (number of sites, distance apart)	Typical Sampling duration (simultaneous sampling at sites?)	Metres from highway/s (spatial extent of study area)	Main findings and recommendations
2008	Zhu et al.	Camden, NJ, USA (I-676)	80,000/day (6)	VOCs (28, 150 - 200 m)	1 - 2 days, over summer and winter (yes)	120 m - 1.5 km (2.5 km^2)	Both mobile sources and some of the stationary sources contributed to ambient BTEX and MTBE. Sampling at the fixed monitoring site may under- or over-estimate air pollutant levels in a ''hot spot'' area, suggesting that the ''spatial saturation sampling'' is necessary for conducting accurate assessment of air pollution and personal exposure in a community with a high density of sources.
2011	Al Madhoun et al.	Sungai Kecil, Malaysia (E1, P144) Nibong Tebal, Malaysia (1)	1,400/hr (4) 1,250/hr (4)	Benzene (2, 10 - 350 m) Benzene (3, 10 - 500 m)	1 hour, twice over one day (yes) 1 hour, twice over one day (yes)	10 - 20 m (1.5 km^2) 10 - 520 m (2 km^2)	Concentrations were higher near the highways than at setback sites by a factor of ~2. Traffic composition showed that the main contributors to traffic flow were cars and motorbikes and they are major contributors to benzene emissions as well.
2011	Lawson et al.	Melbourne, Australia (M1, M3, M11)	30,000 - 73,000/day (4 - 6)	CO, NO_2, $PM_{2.5}$, PM_{10}, BTEX (15, varying)	1 week continuous, over 8 months (no)	< 50 m > 300 m (300 km^2)	No elevation of CO, benzene, ethylbenzene or xylenes inside or outside near-road (< 50 m) homes. Possibly due to low traffic volumes and the siting of instrumentation in back yards of single-storey detached dwellings. Spatio-temporal variance in the sampling was the biggest limitation in detecting roadway influence.
2012	Wang et al.	Rochester, NY, USA (I-490, I-590)	112,291/day (6) 112,549/day (8)	UFPs, 5.6 - 560 nm, (12, varying)	1 week continuous, once per each of the four seasons (only partly)	50 m - 4.5 km (18 km^2)	Elevated UFP number concentrations were observed near highways, off-road diesel engines, and residential wood combustion sources, indicating significant

							contributions to the UFP exposure of people living adjacent to these sources. Results suggest that one stationary monitoring site may not represent the actual human UFP exposure over a whole urban area.
2013	Barros et al.	Porto, Portugal (VCI)	7,000/hr - 107,000/day (8)	NO_2, benzene (40, 150 m max.)	3 weeks, once per season during spring, winter and autumn (yes)	≤ 100 m (3 x areas, 0.08, 0.20 and 0.48 km^2)	At 100 m, 81.8% of NO_2 receptors exceed the annual WHO limit - at the roadside this value was 95.5%. Findings suggest that the safe distance to an urban motorway roadside should be at least 100 m. This distance should be further studied before being used as a reference to develop articulated urban mobility and planning policies.
2013	Clougherty et al.	New York City, NY, USA (numerous)	Not stated	NO_x, BC, $PM_{2.5}$, SO_2 (155, not stated)	2 weeks, six per each of the four seasons (yes)	Not stated (130 km^2)	Densities of total traffic, truck traffic, oil burning boilers and industrial space explained 65% of BC variation. Traffic density described 67% of nitrogen dioxide variation. Chronic exposure disparities and unique local sources can be identified through year-round saturation monitoring.
2013	Fuller et al.	Somerville, MA, USA (I-93)	150,000/day (8)	PNC, 6 nm - 3 µm, (18, varying)	7 - 21 days over 172 days, spring, summer, autumn (no)	< 100 m 100 - 400 m > 1000 m (10.6 km^2)	Homes < 100 m had higher indoor/outdoor PNC compared with homes > 1000 m. A 10% increase in outdoor PNC equaled an 11% increase in indoor PNC. These results may have significance for estimating indoor, personal exposures to traffic-related air pollution.

Table 2.9 Summary of spatial saturation (or partial saturation) studies featuring major highways - mobile measurements

Year	Authors	Location (major highways in area)	Mean traffic volume (lanes)	Pollutant/s measured (vehicle used)	Typical sampling duration	Metres from highway/s (spatial extent of study area, route distance)	Main findings and recommendations
2004	Kolb et al.	Boston, MA, USA (I-93)	~150,000/day (8)	NO, NO_2, N_20, CO_2, CH_4 (2002 GMC Workhouse F.C, diesel engine)	Unspecified, over 1 day	0 - 4 km (20 km^2, not stated)	Data were smoothed to produce maps representative of well-mixed urban levels but study noted high concentrations at busy roads dominated by traffic sources.
2008	Ash	Somerville, MA, USA (I-93)	~8,000/hr, ~150,000/day (8)	UFPs, PNC (7 nm - 2.5 µm), NO_x, CO, CO_2, 0_3, AVOC (2002 GMC Workhouse F.C, diesel engine)	5 hours, over 1 day	0 - 415 (~0.14 km^2, not stated)	Small scale spatial and short-term temporal variations in both upwind and downwind UFP and gaseous pollutant levels. UFP, PNC, CO, CO_2 and NO_x concentrations generally decreased with distance from highway. Levels were highest from 6 - 7 AM, remaining elevated ~300 m downwind and ~75 m upwind of the highway. AVOC did not vary with space and time.
2008	Baldauf et al.	Raleigh, NC, USA (I-440)	125,000/day (8)	UFPs (20 nm, 75 nm), (Duke University Mobile Lab - van, engine unspecified)	Not stated	0 - 400 m (~0.16 km^2, not stated)	Sharp UFP gradients away from the road. Significant decrease in UFP concentrations immediately behind a noise barrier (compared to no noise barrier), with winds from the roadway.
2009	Buonocore et al.	Boston, MA, USA (Huntington Avenue)	~420/hr (4)	UFPs (6 - 100 nm), $PM_{2.5}$, PAH (pedestrian sampling)	2 hrs, twice per day, over ~50 days	0 - 800 m (~6 km^2, varying)	Ultrafine particles decreased by 50% within 400 metres of 2 major roadways. Unlike fine particulate matter, ultrafine particles demonstrate significant spatial and temporal variability within an urban neighbourhood, contributing to environmental justice concerns.
2009	Kozawa et al.	West Long Beach, CA, USA (I-710)	~11,000 - 13,000/hr - truck traffic only (6)	UFPs (5 - 560, 10 nm - 1 µm), BC, NO_x, NO, NO_2, pPAH, CO, CO_2, VOCs (Toyota RAV4 sub-SUV electric vehicle)	2.5 hrs twice per day, over 24 days during the winter and summer seasons	0 - 9 km (~75 km^2, ~48 km)	Diesel-related concentrations of BC, NO, UFPs and pPAH were frequently elevated 2 - 5 times within 150 m downwind of the freeway (compared to further back) and up to 2 times within 150 m of arterials. Those living or working near and downwind of busy roadways can have several-fold higher exposures than would be predicted by ambient measurements in non-impacted locations.

2010	Bassok et al.	Seattle, WA, USA (I-5, I-90)	300,000/day (8) 18,000/day (4)	BC (gasoline car)	2 hrs each day, over 10 days	0 - 610 m (~ 0.6 km^2, 8 km)	Pollution levels differed substantially across the study area. The results show the need for street-level air pollution monitoring, revisions in current land use and transportation policies, and air quality planning practice.
2010	Durant et al.	Somerville, MA, USA (I-93)	150,000/day (8)	PNC, CO_2, NO, NO_2, O_3, AVOCs	45 - 60 min repeatedly for 5 hours, for 1 day only	0 - 400 m (~0.1 km^2, not stated)	Before sunrise and peak traffic flow rates, downwind concentrations of particles, CO_2, NO, and NO_2 were highest within 100–250m of the highway. After sunrise, pollutant levels declined sharply (e.g., PNC and NO were more than halved) and the gradients became less pronounced as wind speed increased.
2010	Hagler et al.	Durham, NC, USA (I-85)	87,000/day	UFPs (5.6 - 560 nm), CO (PT Cruiser electric vehicle, gasoline Ford Expedition Sport Utility Vehicle)	1.5 - 3 hrs each day, over 1 week	0 - 600 m (~6.5 km^2, 10 km)	High-resolution mapping of CO and UFPs revealed higher concentrations in neighbourhoods less than 150 m from a highway than in areas farther from the road. This is an emerging issue of concern. Meteorology and built environment should be considered in understanding and mitigating exposure to near-road air pollution.
2012	Hu et al.	Boyle Heights, CA, USA (I-5, I-10)	283,000/day	UFPs (5 - 560, 10 nm - 1 µm), $PM_{2.5}$, BC, NO_x, NO, NO_2, pPAH, CO, CO_2, (Toyota RAV4 sub-SUV electric vehicle)	~40 min, twice per day, over 11 days	0 - 5.5 km (19.25 km^2, ~10 km)	A residential area characterised by an unusually dense set of traffic sources. Reported an overall mean UFP concentration across the area as ~33,000 pt/cm^3. This UFP cloud was attributed to heavy duty trucks and high-emitting vehicles. Highlights how multiple factors combine to create important human exposure assessment implications.
2012	Kozawa et al.	West Long Beach, CA, USA (I-710)	~760/hr - truck traffic only (6)	UFPs (5.6 - 560 nm) (Toyota RAV4 sub-SUV electric vehicle)	2 hrs each day, over 14 days	0 - 700 m (0.4 km^2, varying)	Parallel wind conditions appeared to promote formation of broader and larger size distributions of roughly one-half the particle concentration. Multivariate analysis of several variables found meteorology, particularly wind direction and temperature, to be important in predicting UFP concentrations within 150 m of a freeway.

2012	Padró-Martínez et al.	Somerville, MA, USA (I-93)	150,000 (8)	PNC, $PM_{2.5}$, pPAH, BC, CO, NO, NO_x (2003 Chevrolet, gas engine)	1/hr, 6 times per day, over 55 days	0 - 400 m (near-highway) > 1000 m (urban background) (2.3 km^2, 15.4 km)	Highest pollutant concentrations measured within 0 - 50 m. PNC levels two-fold higher than in background areas. PNC highest in winter, lowest in summer. Similar spatial and temporal trends for NO, CO and BC but not for $PM_{2.5}$. Datasets containing fine-scale temporal and spatial variation of air pollution levels near highways may help to inform exposure assessment efforts.
2013	Banks	Albuquerque, NM, USA (I-40)	~10,000/hr (8)	PNC, pPAH, O_3, NO_x, NO, CO, CO_2, VOCs (2012 Ford Escape, gas engine)	2 - 4 hrs each day, over 7 days	30 m - 4 km (~70 km^2, not stated)	Two distinctive dispersion patterns were captured: 1) a symmetric pattern on either side of the interstate associated with low wind speeds; and 2) an asymmetric pattern with a dominant downwind influence. An expected decline with distance from roadway for several traffic-related pollutants, indicative of the dispersion process, was observed for the downwind near-roadway region. Elevated vehicle-emitted pollutants within the first ~100 meters of the roadway, declining to background levels at 300 m+.
2013	Peters et al.	Antwerp, Belgium (E-34)	Not provided (8 - 9) *The focus was on the local street network*	UFPs (20 nm - 1 μm), PM_{10} (bicycle)	~25 min, varying runs per day, over 8 days	~500 m - 1.5 km (3 km^2, 5 km)	Significant spatial variation in UFP concentrations were reported but not for PM_{10}. A limited set of about 20 mobile measurements carried out on different days and different times of the day allows to distinguish streets with higher and lower median concentrations of UFP in a significant way.

2014	Levy et al.	Montreal, QC, Canada (40, 25 15, 13, 20)	Not provided (4 - 6, plus 4 - 6 parallel link way lanes) *The focus was on the entire area*	UFPs, BC, OM, $PM_{1.0-10}$, O_3, CO, SO_2, NO_z, NO_y, NO_x, NO, NO_2, VOCs, O_x, HOA, MZ57 (GMC C7500 medium duty diesel truck)	34 days over winter, summer and autumn	0 - 6 km (two routes covering ~35 km^2 and ~60 km^2 - length not stated)	Average correlations for the combustion-related pollutants (nitrogen species, UFP, BC, and HOA), which in most areas are strongly linked to traffic, were highest in the high-traffic, highway-influenced Anjou neighborhood. $PM_{2.5}$ had a higher average correlation with other pollutants in the low-traffic, less industrially influenced Riviere des Prairies neighborhood than in the Anjou neighborhood. The nitrogen species (NO, NO_2, NO_x) continue to be the best compromise as proxy measures of urban-scale variability in chronic exposures to complex urban air pollution mixtures.

2.7 Daily personal exposure to traffic pollutants

Very few studies have adequately measured 24-hour daily personal exposure to markers of traffic pollution and only four monitoring studies were identified as suitable for inclusion (Table 2.10). The main barriers to this are that reliable portable instruments are obtrusive, require training to run and can have limited temporal logging capacity due to small internal memory and requiring the user change filters or top up chemicals. The quality of the measurements also depend on the participant's commitment to carrying the instruments with them, as well as keeping accurate notes of time spent in different environments. An alternative option is to attach small, passive samplers to a participant's clothing, but these only return a single mean value with no information on the influence of each type of microenvironment. However, where there is a large enough participant base, with clear differences across activity patterns, some meaningful observations can be made. In Perth, Australia, Horton et al. (2006) recruited 50 participants to wear passive benzene samplers 24-hours per day for one week. They observed statistically significant positive relationships between frequency of petrol refuelling, time spent in enclosed car parks and time spent commuting.

In a childhood asthma study in the South Bronx, NY, USA, personal exposure to $PM_{2.5}$ and EC were monitored for 10 inner-city children over the course of a week using active sampling (drawing air via an inlet) instruments mounted to the handles of rolling backpacks (Spira-Cohen et al. 2010; Spira-Cohen et al. 2011). Although time-activity diaries were kept, like passive sampling, the instruments used only provided 24-hour integrated samples, rather than continuous measurements. Continuous data were collected using FEM equipment at the participants' schools, but these data were averaged to match the integrated personal samples. This South Bronx area is home to three busy six-lane highways (I-87, I-278 & I-895, AADT > 100,000) and features schools as close as ~50 m away. The authors found a statistically significant linear relationships between both school and residential proximity (to highways), and EC exposure. In addition, close highway proximity was associated with heightened asthma exacerbations among children compared to those living further away (≤ 150 m versus 150 - 300 m). It is possible that this is the only published research that has employed daily personal non-passive sampling to specifically investigate residential near-highway, integrated personal exposures.

Another notable study was that by Braniš & Kolomazníková (2010), who monitored an adult female's $PM_{2.5}$ exposure for an entire year while living in Prague, Czech Republic. Mass $PM_{2.5}$ concentrations were logged every five minutes for entire days, for as many days of each month as technically possible, using an active sampling instrument (TSI 8520) mounted inside a wearable backpack with a sampling inlet located near the participant's mouth. The highest mean concentrations were recorded for indoor microenvironments with combustion sources (restaurants, homes with stoves), while concentrations for the transport microenvironment were no different to other outdoor activities, including a summer camp. Exposures were lowest at the participant's home environment - a clean city apartment with few indoor sources. Although these results are less relevant to traffic exposures, this study design could be replicated for near-highway residents sampling fresh emissions markers. This would greatly improve understandings of the actual long-term exposure risks of near-highway living compared to time spent in other environments.

As a result of the obvious difficulties associated with personal monitoring, exposure modelling is often the preferred approach. In the past, the vast majority of these have used LURs or exposure models to assign mean concentrations to large populations, across wide urban areas. More recently, personal models are helping improve exposure classification by properly accounting for the movement of single individuals through space and time (Table 2.11). The advantage of personal modelling over population modelling is that behaviours leading to exposure differences between those who live in very close proximity (same household, next door, etc.), can be identified. As demonstrated by Dons et al. (2014), exposures for an inactive near-highway resident may not be any greater than someone who lives in a background location but spends a significant time commuting to work each day.

Depending on the number of microenvironments simulated, personal exposure models usually require a large number of parameter inputs. Microenvironmental parameters (AERs, infiltration factors, etc.) and microenvironmental concentrations are frequently borrowed from other studies in different regions of the world, due to the difficulty of collecting the complete dataset required for a local simulation. The remaining inputs may be made of up a combination of locally monitored ambient data, meteorological data, dispersion modelled data, personal measurements, indoor exposure models and commuting exposure models.

Of the nine personal modelling studies found, only one targeted a near-highway population. Vette et al. (2013) used a combination of ambient and indoor modelling to simulate exposures for 139 asthmatic children living ≤ 150 m and between 150 and 300 m of busy highways (AADT > 90,000) in Detroit, MI, USA. Initial results indicate elevated BC and $PM_{2.5}$ concentrations for those who live, and attend schools, closest to the roads. It should be emphasised that these results are unlikely to be transferable to an adult population. Adults have much more varied exposure profiles due to greater mobility, compared to young children who often live, recreate and attend school within the primary study zone.

This section has followed on from the shortcomings of other exposure classification approaches discussed in the previous section and subsequently identified a major research gap. Not only are there very few personal monitoring studies, but there is also a paucity of personal exposure modelling research. Authors of the more recent papers all agree that personal modelling approaches will help reduce uncertainties in exposure classifications and be of use to epidemiological research and local air quality management (Dias & Tchepel 2014; Dionisio et al. 2013; Hannam et al. 2013; Vette et al. 2013). The increased availability of ambient monitoring data and recent improvements in microenvironment modelling approaches has helped advanced personal exposure models to the point where researchers are now achieving good validation results (Dias & Tchepel 2014). Since the health risks of living near highways are still not properly understood, quantifying the relative risk posed compared to living elsewhere and working in varying occupations, requires assessment.

Table 2.10 Summary of daily personal exposure monitoring studies

Year	Authors	Location (major highways in area)	Methods employed	Study Population	Metres from Roadway (proximity subjects reside in)	Pollutants measured (if any)	Duration of study	Main findings
2006	Horton et al.	Perth, WA, Australia	Personal sampling Generalised linear modelling	50 adults	Not stated	Benzene	5 days during summer, 5 days during winter	The mean benzene exposure of the participants in summer was 1.76 and 1.98 mg/m^3 in winter. Refuelling and commuting were the most significant contributors to non-industrial exposure to benzene in summer and winter for Perth residents.
2010	Braniš & Kolomazníková	Prague, Czech Republic	Personal sampling	1 adult female	Not stated	$PM_{2.5}$	1 year	Mean year-long result was 14.9±52.5 μg/m^3. Highest mean concentrations were detected in restaurant microenvironments (294.4 μg/m^3), while the next highest was in an indoor microenvironment heated by wood and coal stoves (112.2 μg/m^3). Lowest means were detected outdoors in a rural environment (7.0 μg/m^3) and indoors at the monitored person's home (9.3 μg/m^3).

2010 2011	Spira-Cohen et al.	New York City, NY, USA (I-87, I-278, I-895)	Personal sampling Personal diaries of wheeze, cough and shortness of breath	40 children, aged 10 - 12 yrs	School situated 53 m from I-87 School situated 736 m from I-278	EC, $PM_{2.5}$	1 month sampling at each of four schools	Adverse health associations were strongest with personal measures of EC exposure, suggesting that the diesel "soot" fraction of $PM_{2.5}$ is most responsible for pollution-related asthma exacerbations among children living near roadways. Studies that rely on exposure to PM mass may underestimate PM health impacts.
2011	Yazar et al.	Stockholm, Sweden	Personal sampling	40 adults, aged 20 - 50 yrs	Not stated	NO_x, NO_2, benzene, 1,3-butadiene, benz(a)pyrene	1 week samples, measured over 4 months	Personal exposure to NO_x and NO_2 were higher than urban background levels, but the NO_2 exposure level was lower than traffic site levels. Benz(a)pyrene showed lower concentrations indoors compared to outdoor levels, although a significant correlation was found between indoor and outdoor levels.

Table 2.11 Summary of daily personal exposure modelling studies

Year	Authors	Location (major highways in area)	Methods and models employed	Study Population (number of microenvironments)	Metres from Roadway (proximity subjects reside in)	Pollutants measured (if any)	Duration of study	Main findings
1985	Spengler et al.	Kingston and Harriman, TN, USA (I-40, H-61)	Personal monitoring Deterministic, predictive modelling	101 adults (4)	Not stated	RSP	38 days sampling, over 46 days	Modelling based time spent in 4 microenvironments and measured concentrations explained 64% of the variance in exposures. Ambient concentrations provide poor prediction of personal exposures respirable size particles. Investigations must consider indoor environments in estimating subject exposures.
2004	Bruinen de Bruin et al.	Milan, Italy	Personal monitoring Time-activity dairies EXPOLIS probabilistic model	45 adult office workers (11)	Not stated	CO	2 days	Simulated exposures showed good agreement with 48, 24, 8 and even 1 hr ambient measurements, possibly due to model not accounting for indoor sources while the ambient monitors were in heavily-trafficked locations.
2005	Zidek et al.	London, UK	Ambient monitoring pCNEM probabilistic model	2 adult females, smokers (5)	Not stated	PM_{10}	3 months	Estimates from pCNEM could be used for health epidemiology studies, incorporating not only the change in locations, and thus exposures, throughout the day but also providing a measure of uncertainty which could be 'fed-through' into the health analysis and resulting relative risks.

2013	Gerharz et al.	Münster, Germany	Ambient monitoring Air dispersion modelling Personal GPS tracking Time-activity diaries Indoor air modelling Personal monitoring for validation purposes	10 adults	Not stated	PM_{10}, $PM_{2.5}$	1 day	Modelled daily means for PM_{10} were 17 - 126 and 6 - 84 μg/m^3 for $PM_{2.5}$. Good agreement with personal monitoring at temporal resolutions from 5 min to 1 day. Uncertainties in the model results are considerable and increase with higher exposure levels. Large deviations between modelled and measured exposure can often be explained by missing data on indoor emissions or insufficiently detailed activity diaries.
2013	Dionisio et al.	Atlanta, GA, USA	Ambient monitoring AERMOD dispersion modelling Time-activity data Commuting data SHEDS population exposure modelling APEX personal exposure modelling	169 zip code areas	Not stated	NO_x, CO, EC, $PM_{2.5}$, SO_4, O3	3 years	All models exhibited high spatial variability for traffic-related pollutants (CO, NO_x, and EC), but little spatial variability for regional pollutants ($PM_{2.5}$, SO_4, and O_3). If temporal variability is interest in an epidemiological application, the use of estimates from either model may yield similar results. Models incorporating infiltration parameters, time-location activity budgets, and other exposure factors affect the magnitude and spatiotemporal distribution of exposure, especially for local pollutants. The results of this analysis can inform the development of more appropriate exposure metrics for future epidemiological studies of the short-term effects of particulate and gaseous ambient pollutant exposure in a community.

2013	Vette et al.	Detroit, MI, USA (I-96, I-94, I-75)	Ambient monitoring Indoor monitoring AER measurements EMI	139 asthmatic children	< 150 m < 300 m School ~200 m from I-75	NO_x, CO, BC, $PM_{2.5}$	16 days	$PM_{2.5}$ mass and BC concentrations exhibited spatial variations that are consistent with roadway and diesel impacts expected throughout the study domain. Integrated monitoring and modelling provides insight into the level of exposure information necessary for epidemiology studies. This approach helps reduce will reduce uncertainties in health risk assessments related to ambient pollution and provide useful information for federal and state/local air quality management strategies.
2013	Hannam et al.	Manchester & Blackpool, UK	Personal monitoring DEFRA modelling GIS modelling/interpolation techniques - IDW, OK LUR, with roadway covariates	85 pregnant women	Not stated	NO_x, NO_2	48 hr personal 146 days ambient	Personal exposure was most strongly correlated with DEFRA, OK and IDW (NO_2, NO_x r = .60 - .62). Where there is evidence for high temporal variability in exposure, methods of exposure estimation which focus solely on spatial methods should be adjusted temporally as it will improve exposure estimates.
2014	Dias & Tchepel	Leiria, Portugal	Personal GPS monitoring Time-activity patterns GIS Infiltration factors Emission modelling Air dispersion modelling ExPOSITION modelling	5 individuals (6)	Not stated	$PM_{2.5}$	1 day	The results obtained for daily average individual exposure correspond to a mean value of 10.6 $\mu g/m^3$. The use of point air quality measurements for exposure assessment will not explain the intra and inter-variability of individuals' exposure levels. This work provides a time sequence of the exposure events thus linking exposures to activities with high spatio-temporal resolution.
2014	Dons et al.	Flanders region, Belgium	Personal monitoring GPS monitoring Transport microenvironment model	62 individuals (3)	Not stated	BC	7 days	Inhaled doses were similar for both high SES and low SES groups. This analysis suggests that differences in health impact between the groups are almost completely explainable by increased

			Indoor air model Traffic metrics LUR					susceptibility to air pollution health effects, and not by increased air pollutant intake.

2.8 Community perceptions of traffic-impacted air quality

Research assessing community perceptions of traffic-impacted air quality is very scarce and only four studies were identified, with all but one completed in the UK and none outside of Europe (Table 2.12). Considering the growing interest in environmental justice, it is somewhat surprising that there is little examination into the perspectives of near-highway residents. This is probably explained by the literature suggesting that for those residing proximate to busy roadways, strong concern is mostly restricted to a minority whom have underlying health conditions (Day 2006). For the rest of the population, there appears to be a general apathy towards potential health risks, with the exception of those who have children or unwell family members (Day 2006). Presumably this apathy exists because a sizable proportion of residents will be renting their properties and not planning on staying long-term, coupled with the fact that any potential health effects are not obvious to them. For neighbourhoods near high-volume roads in the Sunderland area of England, UK, only one-fifth of residents rated air quality as worse than 'Good', despite 90% stating traffic was the major emissions source in their area. There also seems to be a general perception that residents associate poorer air with inner-city areas of heavy traffic congestion and poor dispersion due to high buildings (Bickerstaff & Walker 2001). Although this assumption is correct, there could be a lack of awareness regarding elevated concentrations near highways during low wind speed periods. Bickerstaff & Walker (2001) indicate this could be the case, suggesting limited lay understandings of more advanced processes of dispersion. Another factor is that most residents have a positive relationship with the highway as a result of increased accessibility. In a survey of 1225 residents < 1000 m from highways in the Netherlands, the authors reported an overall positive attitude, with only those within the first 300 m having strong perceptions of noise and air quality impacts (Hamersma et al. 2014). However, the key criticism of studies like this (and others in Table 2.12) is that the bulk of survey respondents live way outside the 'immediate zone of influence' (< 150 - 300 m) consistently identified by most previous near-highway studies (Tables 2.3 - 2.5). Including only two measures of proximity (close to highway, far from highway) is unlikely to adequately illustrate concerns relative to the exponential decay patterns exhibited by traffic pollutants and noise, which are highly correlated (Shu et al. 2014).

One consistent theme throughout the studies that have been done, is that residents possess a strong knowledge of associated health impacts, irrespective levels of income and education (Day 2006; Howel et al. 2003). Knowing that thousands of people live in these near-highway corridors, and that exposure to traffic fumes and noise is associated with stress and adverse physical health effects, more work needs to be done to properly evaluate the psychological impacts.

Table 2.12 Summary of studies on community perceptions of traffic-affected air quality

Year	Authors	Location (major highways in area)	Methods employed	Study Population	Main findings
2001	Bickerstaff & Walker	Birmingham, UK	Questionnaire survey One-to-one interviews	378 residents 50 residents	40% thought air quality in the city was worst close to roads and motorways (30%) or industry (10%). This indicates air quality perception is spatially bound and corresponds to a source-directed distance-decay relationship, with limited weight attached to more complex processes of environmental dispersion. The inner-city was seen as the most polluted area due to assumed pollution concentration - buses, taxis etc - and high density built environment, which limits dispersion. The lack of green space in the inner city was said to factor into this perception too.
2003	Howel et al.	Teesside and Sunderland, UK	Mail-out survey	2,744 residents	Traffic, rather than industry, was viewed as the major source of local air pollution in all but one of five neighbourhoods. For one area, 90% rated traffic as the major source but only 21% said that air quality was any worse than 'Good'. Comparatively, in the South Bank area, 86% said that industry was the major source and 87% stated air quality was worse than 'Good'. Proximity to industry was related to participants being more likely to give poor ratings. Only weak associations were found when contrasting responses by material deprivation. This suggests proximity plays a stronger role than the assumption that greater exposure to hazards by lower income groups leads to increased risk awareness.
2006	Day	London, UK	Qualitative interviews in order to develop a quantitative survey Mail-out survey	~45 residents 200 residents	Most prevalent health effect to emerge was respiratory issues, followed by allergies and irritations. Those suffering from asthma or other underlying illnesses had heightened perceptions regarding the link between traffic pollution and health effects. More than 80% of respondents said air pollution was linked to respiratory and allergy problems, while only 42, 33 and 19% agreed air pollution could cause cancer, heart disease and memory issues, respectively. Beliefs appeared to be formed by making associations between air quality and symptoms evident in themselves or people they knew.

2014	Hamersma et al.	The Netherlands	Ambient monitoring Surveys Ordinal regression	1225 residents 0 - 300 m from highways < 1000 m from highways	Perceived air pollution and noise impacts had a comparably strong impact for those in close proximity to highways, but overall, residents showed positive attitudes towards highways due to increased accessibility.

2.9 Summary

This literature review summarises many of the key studies relevant to the exposure science of quantifying traffic emissions impacts on near-highway residents', using several criteria to narrow down the selection (Table 2.1). There is a clear consensus across studies assessing near-highway decay, that concentrations of primary vehicle emissions, such as gases (NO_x, NO_2, CO) and fine particulates (PNC ≤ 1 μm), decay exponentially to ~50% of roadside concentrations by 150 m and may reach background levels by 300 m, under regular daytime meteorological conditions (Tables 2.3 - 2.5). This is generally consistent throughout cities around the world. However, the short-term sampling strategies employed by most studies may exaggerate gradients as recent long-term monitoring has shown a mean reduction of only ~30% by 300 m downwind (Kimbrough et al. 2013). Furthermore, mobile monitoring has shown the spatial extent away from highways can reach at least 2.6 km downwind during early pre-sunrise hours (Hu et al. 2009). Consequently, when evaluating exposures and potential health effects, researchers may need to focus on a wider highway corridor area of impact than the ≤ 150 m or ≤ 300 m used in some studies (Bae et al. 2007; Vette et al. 2013). The main certainty at this time is that residents living adjacent to major highways face higher at-residence exposures than those living further away and the pollutant mixture (gas ratios, particle sizes, etc.) differs with distance due to changes in chemical composition and particle coagulation (Zhang et al. 2004).

While there is a clear need to protect human health interests, current evidence is insufficient to confirm a causative link between near-highway living and any detrimental health outcomes other than the exacerbation of childhood asthma (HEI 2010). Nonetheless, there are several serious and potentially fatal health effects involving the cardiovascular and pulmonary systems, for which the evidence is thoroughly suggestive and leaning towards a causative link. The influence of noise and subsequent stress outcomes is somewhat difficult to disentangle from the emissions impacts, as these factors can increase susceptibility (Clougherty et al. 2013; Sørensen et al. 2012).

Despite the uncertainties, there is sufficient cause for concern for the health of long-term residents, children, the elderly and those with pre-existing health issues. Spatial analyses have shown that minority populations and the poor are disproportionately represented in highway corridor zones, throughout much of the United States (Rowangould 2013; Tian et al. 2013). In other parts of the world, the relationship is reversed, with the wealthiest residential areas exposed to the highest traffic volumes (Cesaroni et al. 2010; Habermann et al. 2014). Whether these environmental justice studies truly represent total disparities between groups is questionable because exposure at place of residence is only one part of the complete daily exposure profile.

Recently there have been increasing efforts to improve classification by stringing together a number of microenvironment exposure models (indoor, in-traffic, at work) to better represent how mobility and time spent in high concentration environments, affects daily mean exposure. Some results suggest that living in cleaner background air environments further away from work can result in similar exposures to those living right next to large freeways, as increased time in the extreme exposure environment during the commute substantially increases the daily mean (Dons et al. 2012). It follows that increased commute times can also elevate long-term stress levels, perhaps to a similar extent of near-highway living.

This review has identified several areas in which there is limited knowledge and a clear need for further enquiry.

- Long-term, near-highway monitoring is very limited and very short measurements of decay profiles likely misrepresent the risks as they are performed during the heaviest traffic flows, which does not represent the entire day. Residents are also more likely to be at work during these times.

- Spatial saturation studies seek to better describe near-highway decay gradients but, like gradient profiling with a series of monitors, most of the work so far has also been restricted to peak times when the most extreme spatial contrasts are captured.

- Exposure inequity research should focus on finer-scale near-highway variation, as only having one or two measures of proximity does not adequately represent pollutant decay. There is almost a complete lack of environmental justice research relating to traffic emissions in Australasia and the work that has been done used oversized spatial units.

- Potential exposure inequities require better-refined assessment through use of more complete exposure models rather than simply using the home address to attribute disproportionate urban exposure.

- Throughout the health literature, less attention has been paid to the psychological effects of near-highway life and how that affects long-term health. Little is known about the proximity-to-source to level-of-concern relationship and how far away major concern subsides.

The chapters that follow attempt to partially address these knowledge gaps by making a significant contribution to the understandings of an ultra-complex field of enquiry.

References

Aksoy, M 1985, 'Malignancies due to occupational exposure to benzene', *American Journal of Industrial Medicine,* vol. 7, no. 5-6, pp. 395-402.

Al Madhoun, W, Ramli, N, Yahaya, A, Yusuf, N, Ghazali, N & Sansuddin, N 2011, 'Levels of benzene concentrations emitted from motor vehicles in various sites in Nibong Tebal, Malaysia', *Air Quality, Atmosphere & Health,* vol. 4, no. 2, pp. 103-9.

Andersen, ZJ, Raaschou-Nielsen, O, Ketzel, M, Jensen, SS, Hvidberg, M, Loft, S, Tjønneland, A, Overvad, K & Sørensen, M 2012, 'Diabetes Incidence and Long-Term Exposure to Air Pollution: A cohort study', *Diabetes Care,* vol. 35, no. 1, pp. 92-8.

Ash, C 2008, *Spatial and temporal variations in ultrafine particulate matter and other air pollutants throughout the morning near a major highway*, M.S Thesis, Tufts University.

Baccarelli, A, Martinelli, I, Pegoraro, V, Melly, S, Grillo, P, Zanobetti, A, Hou, L, Bertazzi, PA, Mannucci, PM & Schwartz, J 2009, 'Living near major traffic roads and risk of deep vein thrombosis', *Circulation,* vol. 119, no. 24, pp. 3118-24.

Bae, CHC, Sandlin, G, Bassok, A & Kim, S 2007, 'The exposure of disadvantaged populations in freeway air-pollution sheds: a case study of the Seattle and Portland regions', *Environment and Planning B: Planning and Design,* vol. 34, no. 1, pp. 154-70.

Baldauf, R, Thoma, E, Hays, M, Shores, R, Kinsey, J, Gullett, B, Kimbrough, S, Isakov, V, Long, T, Snow, R, Khlystov, A, Weinstein, J, Chen, FL, Seila, R, Olson, D, Gilmour, I, Cho, SH, Watkins, N, Rowley, P & Bang, J 2008, 'Traffic and meteorological impacts on near-road air quality: Summary of methods and trends from the Raleigh near-road study', *Journal of the Air and Waste Management Association,* vol. 58, no. 7, pp. 865-78.

Banks, L 2013, *Characterization of Traffic-Related Air Pollutants near a Major Roadway in Albuquerque Using a Mobile Monitoring Approach*, Masters Thesis, University of Washington.

Barros, N, Fontes, T, Silva, MP & Manso, MC 2013, 'How wide should be the adjacent area to an urban motorway to prevent potential health impacts from traffic emissions?', *Transportation Research Part A: Policy and Practice,* vol. 50, pp. 113-28.

Bassok, A, Hurvitz, PM, Bae, CHC & Larson, T 2010, 'Measuring neighbourhood air pollution: The case of Seattle's international district', *Journal of Environmental Planning and Management,* vol. 53, no. 1, pp. 23-39.

Beelen, R, Hoek, G, van den Brandt, PA, Goldbohm, RA, Fischer, P, Schouten, LJ, Jerrett, M, Hughes, E, Armstrong, B & Brunekreef, B 2008, 'Long-term effects of traffic-related air pollution on mortality in a Dutch cohort (NLCS-AIR study)', *Environ Health Perspect,* vol. 116, pp. 196 - 202.

Bickerstaff, K & Walker, G 2001, 'Public understandings of air pollution: the 'localisation' of environmental risk ', *Global Environmental Change,* vol. 11, pp. 133-45.

Birmili, W, Alaviippola, B, Hinneburg, D, Knoth, O, Tuch, T, Borken-Kleefeld, J & Schacht, A 2009, 'Dispersion of traffic-related exhaust particles near the Berlin urban motorway – estimation of fleet emission factors', *Atmospheric Chemistry and Physics,* vol. 9, no. 7, pp. 2355-74.

Blumer, MB, W; Reich, T 1977, 'Polycyclic Aromatic Hydrocarbons in Soils of a Mountain Valley: Correlation with Highway Traffic and Cancer Incidence', *Environmental Science and Technology,* vol. 11, no. 12, pp. 1082-4.

Braniš, M & Kolomazníková, J 2010, 'Monitoring of long-term personal exposure to fine particulate matter (PM2.5)', *Air Quality, Atmosphere and Health*, pp. 1-9.

Brereton, F, Clinch, JP & Ferreira, S 2008, 'Happiness, geography and the environment', *Ecological Economics,* vol. 65, no. 2, pp. 386-96.

Brugge, D, Lane, K, Padro-Martinez, L, Stewart, A, Hoesterey, K, Weiss, D, Wang, D, Levy, J, Patton, A, Zamore, W & Mwamburi, M 2013, 'Highway proximity associated with cardiovascular disease risk: the influence of individual-level confounders and exposure misclassification', *Environmental Health,* vol. 12, no. 1, p. 84.

Bruinen de Bruin, YB, Hanninen, O, Carrer, P, Maroni, M, Kephalopoulos, S, di Marco, GS & Jantunen, M 2004, 'Simulation of working population exposures to carbon monoxide using EXPOLIS-Milan microenvironment concentration and time-activity data', *Journal of Exposure Analysis and Environmental Epidemiology,* vol. 14, no. 2, pp. 154-63.

Bullen, C, Kearns, RA, Clinton, J, Laing, P, Mahoney, F & McDuff, I 2008, 'Bringing health home: Householder and provider perspectives on the healthy housing programme in Auckland, New Zealand', *Social Science & Medicine,* vol. 66, no. 5, pp. 1185-96.

Buonocore, JJ, Lee, HJ & Levy, JI 2009, 'The influence of traffic on air quality in an urban neighborhood: a community-university partnership', *American Journal of Public Health,* vol. 99, no. 3, pp. S629-35.

Buzzelli, M & Jerrett, M 2004, 'Racial gradients of ambient air pollution exposure in Hamilton, Canada', *Environment and Planning A,* vol. 36, no. 10, pp. 1855-76.

Buzzelli, M & Jerrett, M 2007, 'Geographies of susceptibility and exposure in the city: environmental inequity of traffic-related air pollution in Toronto', *Canadian Journal of Regional Science,* vol. 30, pp. 195-210.

Carrier, M, Apparicio, P, Séguin, A-M & Crouse, D 2014, 'Ambient air pollution concentration in Montreal and environmental equity: Are children at risk at school?', *Case Studies on Transport Policy*, vol. 2, no. 2, pp. 61-69.

Cesaroni, G, Badaloni, C, Romano, V, Donato, E, Perucci, C & Forastiere, F 2010, 'Socioeconomic position and health status of people who live near busy roads: the Rome Longitudinal Study (RoLS)', *Environmental Health,* vol. 9, no. 1, p. 41.

Cheer, T, Kearns, R & Murphy, L 2002, 'Housing policy, poverty, and culture: 'discounting' decisions among Pacific peoples in Auckland, New Zealand', *Environment and Planning C: Government and Policy,* vol. 20, no. 4, pp. 497-516.

Chiu, Y-HM, Bellinger, DC, Coull, B, Anderson, S, Barber, R, Wright, RO & Wright, RJ 2013, 'Associations between Traffic-Related Black Carbon Exposure and Attention in a Prospective Birth Cohort of Urban Children', *Environmental Health Perspectives,* vol. 121, no. 7, pp. 859-64.

Clougherty, J, Kheirbek, I, Eisl, H, Ross, Z, Pezeshki, G, Gorczynski, J, Johnson, S, Markowitz, S, Kass, D & Matte, T 2013, 'Intra-urban spatial variability in wintertime street-level concentrations of multiple combustion-related air pollutants: the New york city community Air survey (NYCCAS)', *Journal of Exposure Science and Environmental Epidemiology,* vol. 23, pp. 232-40.

Clougherty, JE, Levy, JI, Hynes, HP & Spengler, JD 2006, 'A longitudinal analysis of the efficacy of environmental interventions on asthma-related quality of life and symptoms among children in urban public housing', *Journal of Asthma,* vol. 43, no. 5, pp. 335-43.

Cole, L & Foster, S 2001, *From the ground up: Environmental Racism and the Rise of the Environmental Justice Movement*, New York University Press, New York.

Crebelli, R, Tomei, F, Zijno, A, Ghittori, S, Imbriani, M, Gamberale, D, Martini, A & Carere, A 2001, 'Exposure to benzene in urban workers: environmental and biological monitoring of traffic police in Rome', *Occupational and Environmental Medicine,* vol. 58, no. 3, pp. 165-71.

Day, RJ 2006, 'Traffic-related air pollution and perceived health risk: Lay assessment of an everyday hazard', *Health, Risk & Society,* vol. 8, no. 3, pp. 305-22.

Dias, D & Tchepel, O 2014, 'Modelling of human exposure to air pollution in the urban environment: a GPS-based approach', *Environmental Science and Pollution Research,* vol. 21, no. 5, pp. 3558-71.

Dionisio, KL, Isakov, V, Baxter, LK, Sarnat, JA, Sarnat, SE, Burke, J, Rosenbaum, A, Graham, SE, Cook, R, Mulholland, J & Özkaynak, H 2013, 'Development and evaluation of alternative approaches for exposure assessment of multiple air pollutants in Atlanta, Georgia', *Journal of Exposure Science and Environmental Epidemiology,* vol. 23, no. 6, pp. 581-92.

Dons, E, Int Panis, L, Van Poppel, M, Theunis, J & Wets, G 2012, 'Personal exposure to Black Carbon in transport microenvironments', *Atmospheric Environment,* vol. 55, pp. 392-8.

Dons, E, Kochan, B, Bellemans, T, Wets, G & Panis, LI 2014, 'Modeling Personal Exposure to Air Pollution with AB2C: Environmental Inequality', *Procedia Computer Science,* vol. 32, pp. 269-76.

Durant, JL, Ash, CA, Wood, EC, Herndon, SC, Jayne, JT, Knighton, WB, Canagaratna, MR, Trull, JB, Brugge, D, Zamore, W & Kolb, CE 2010, 'Short-term variation in near-highway air pollutant gradients on a winter morning', *Atmospheric Chemistry and Physics,* vol. 10, no. 17, pp. 8341-52.

Feychting, M, Svensson, D & Ahlbom, A 1998, 'Exposure to motor vehicle exhaust and childhood cancer', *Scandinavian Journal of Work, Environment and Health,* vol. 24, no. 1, pp. 8-11.

Finkelstein, MM & Jerrett, M 2007, 'A study of the relationships between Parkinson's disease and markers of traffic-derived and environmental manganese air pollution in two Canadian cities', *Environmental Research,* vol. 104, no. 3, pp. 420-32.

Fuller, CH, Brugge, D, Williams, PL, Mittleman, MA, Lane, K, Durant, JL & Spengler, JD 2013, 'Indoor and outdoor measurements of particle number concentration in near-highway homes', *Journal of Exposure Science & Environmental Epidemiology,* vol. 23, no. 5, pp. 506-12.

Gan, WQ, Koehoorn, M, Davies, HW, Demers, PA, Tamburic, L & Brauer, M 2011, 'Long-term exposure to traffic-related air pollution and the risk of coronary heart disease hospitalizationand mortality', *Environmental Health Perspectives,* vol. 119, no. 4, pp. 501-7.

Gauderman, WJ, Vora, H, McConnell, R, Berhane, K, Gilliland, F, Thomas, D, Lurmann, F, Avol, E, Kunzli, N, Jerrett, M & Peters, J 2007, 'Effect of exposure to traffic on lung development from 10 to 18 years of age: a cohort study', *The Lancet,* vol. 369, no. 9561, pp. 571-7.

Gerharz, LE, Klemm, O, Broich, AV & Pebesma, E 2013, 'Spatio-temporal modelling of individual exposure to air pollution and its uncertainty', *Atmospheric Environment,* vol. 64, pp. 56-65.

Gilbert, NL, Woodhouse, S, Stieb, DM & Brook, JR 2003, 'Ambient nitrogen dioxide and distance from a major highway', *Science of The Total Environment,* vol. 312, no. 1–3, pp. 43-6.

Glass, DC, Gray, CN, Jolley, DJ, Gibbons, C, Sim, MR, Fritschi, L, Adams, GG, Bisby, JA & Manuell, R 2003, 'Leukemia Risk Associated with Low-Level Benzene Exposure', *Epidemiology,* vol. 14, no. 5, pp. 569-77.

Gruzieva, O, Bergstrom, A, Hulchiy, O, Kull, I, Lind, T, Melen, E, Moskalenko, V, Pershagen, G & Bellander, T 2013, 'Exposure to air pollution from traffic and childhood asthma until 12 years of age', *Epidemiology,* vol. 24, no. 1, pp. 54-61.

Gurram, S, Stuart, AL & Pinjari, AR 2014, 'Impacts of travel activity and urbanicity on exposures to ambient oxides of nitrogen and on exposure disparities', *Air Quality, Atmosphere & Health*, pp. 1-18.

Habermann, M, Souza, M, Prado, R & Gouveia, N 2014, 'Socioeconomic inequalities and exposure to traffic-related air pollution in the city of São Paulo, Brazil', *Cadernos de Saúde Pública,* vol. 30, no. 1, pp. 119 - 25.

Hagler, GSW, Baldauf, RW, Thoma, ED, Long, TR, Snow, RF, Kinsey, JS, Oudejans, L & Gullett, BK 2009, 'Ultrafine particles near a major roadway in Raleigh, North Carolina: downwind attenuation and correlation with traffic-related pollutants', *Atmospheric Environment,* vol. 43, no. 6, pp. 1229-34.

Hagler, GSW, Thoma, ED & Baldauf, RW 2010, 'High-resolution mobile monitoring of carbon monoxide and ultrafine particle concentrations in a near-road environment', *Journal of the Air & Waste Management Association,* vol. 60, no. 3, pp. 328-36.

Hamersma, M, Tillema, T, Sussman, J & Arts, J 2014, 'Residential satisfaction close to highways: The impact of accessibility, nuisances and highway adjustment projects', *Transportation Research Part A: Policy and Practice,* vol. 59, pp. 106-21.

Hannam, K, McNamee, R, De Vocht, F, Baker, P, Sibley, C & Agius, R 2013, 'A comparison of population air pollution exposure estimation techniques with personal exposure estimates in a pregnant cohort', *Environmental Science: Processes and Impacts,* vol. 15, no. 8, pp. 1562-72.

Hart, JE, Garshick, E, Dockery, DW, Smith, TJ, Ryan, L & Laden, F 2011, 'Long-Term Ambient Multipollutant Exposures and Mortality', *American Journal of Respiratory and Critical Care Medicine,* vol. 183, no. 1, pp. 73--8.

Hart, JE, Laden, F, Puett, RC, Costenbader, KH & Karlson, EW 2009, 'Exposure to traffic pollution and increased risk of rheumatoid arthritis', *Environmental Health Perspectives,* vol. 117, no. 7, pp. 1065-9.

Havard, S, Deguen, S, Zmirou-Navier, D, Schillinger, C & Bard, D 2009, 'Traffic-related air pollution and socioeconomic status: a spatial autocorrelation study to assess environmental equity on a small-area scale', *Epidemiology,* vol. 20, no. 2, pp. 223-30

Health Effects Institute 2010, *Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects*, Health Effects Institute, Boston.

Heck, JE, Wu, J, Lombardi, C, Qiu, J, Meyers, TJ, Wilhelm, M, Cockburn, M & Ritz, B 2013, 'Childhood cancer and traffic-related air pollution exposure in pregnancy and early life', *Environmental Health Perspectives,* vol. 121, no. 11-12, pp. 1385-91.

Hitchins, J, Morawska, L, Wolff, R & Gilbert, D 2000, 'Concentrations of submicrometre particles from vehicle emissions near a major road', *Atmospheric Environment,* vol. 34, no. 1, pp. 51-9.

Hoffmann, B, Moebus, S, Mohlenkamp, S, Stang, A, Lehmann, N, Dragano, N, Schmermund, A, Memmesheimer, M, Mann, K, Erbel, R & Jockel, KH 2007, 'Residential exposure to traffic is associated with coronary atherosclerosis', *Circulation,* vol. 116, no. 5, pp. 489-96.

Horton, A, Murray, F, Bulsara, M, Hinwood, A & Farrar, D 2006, 'Personal monitoring of benzene in Perth, Western Australia: The contribution of sources to non-industrial personal exposure', *Atmospheric Environment,* vol. 40, pp. 2596-606.

Houston, D, Wu, J, Ong, P & Winer, A 2004, 'Structural disparities of urban traffic in Southern California: Implications for vehicle-related air pollution exposure in minority and high-poverty neighbourhoods', *Journal of Urban Affairs,* vol. 26, no. 5, pp. 565-92.

Howel, D, Moffatt, S, Bush, J, Dunn, C & Prince, H 2003, 'Public views on the links between air pollution and health in Northeast England', *Environmental Research,* vol. 91, pp. 163 - 71.

Hu, S, Fruin, S, Kozawa, K, Mara, S, Paulson, SE & Winer, AM 2009, 'A wide area of air pollutant impact downwind of a freeway during pre-sunrise hours', *Atmospheric Environment,* vol. 43, no. 16, pp. 2541-9.

Hu, S, Paulson, SE, Fruin, S, Kozawa, K, Mara, S & Winer, AM 2012, 'Observation of elevated air pollutant concentrations in a residential neighborhood of Los Angeles California using a mobile platform', *Atmospheric Environment,* vol. 51, pp. 311-9.

Hu, Z, Liebens, J & Rao, KR 2008, 'Linking stroke mortality with air pollution, income, and greenness in northwest Florida: an ecological geographical study', *International Journal of Health Geographics,* vol. 7, no. 1, p. 20.

Hystad, P, Demers, PA, Johnson, KC, Carpiano, RM & Brauer, M 2013, 'Long-term Residential Exposure to Air Pollution and Lung Cancer Risk', *Epidemiology,* vol. 24, no. 5, pp. 762-72.

Jacobson, J, Hengartner, N & Loius, T 2005, 'Inequity measures for evaluations of environmental justice: a case study of close proximity to highways in New York City', *Environment and Planning A,* vol. 37, pp. 21-43.

Jakovljevic, B, Paunovic, K & Belojevic, G 2009, 'Road-traffic noise and factors influencing noise annoyance in an urban population', *Environment International,* vol. 35, no. 3, pp. 552-6.

Jephcote, C & Chen, H 2012, 'Environmental injustices of children's exposure to air pollution from road-transport within the model British multicultural city of Leicester: 2000–09', *Science of The Total Environment,* vol. 414, pp. 140-51.

Kimbrough, S, Baldauf, R, Hagler, GW, Shores, R, Mitchell, W, Whitaker, D, Croghan, C & Vallero, D 2013, 'Long-term continuous measurement of near-road air pollution in Las Vegas: seasonal variability in traffic emissions impact on local air quality', *Air Quality, Atmosphere & Health,* vol. 6, no. 1, pp. 295-305.

Kingham, S, Longley, I, Salmond, J, Pattinson, W & Shrestha, K 2013, 'Variations in exposure to traffic pollution while travelling by different modes in a low density, less congested city', *Environmental Pollution,* vol. 181, pp. 211-8.

Kingham, S, Pearce, J & Zawar-Reza, P 2007, 'Driven to injustice? Environmental justice and vehicle pollution in Christchurch, New Zealand', *Transportation Research Part D-Transport and Environment,* vol. 12, no. 4, pp. 254-63.

Kolb, CE, Herndon, SC, McManus, JB, Shorter, JH, Zahniser, MS, Nelson, DD, Jayne, JT, Canagaratna, MR & Worsnop, DR 2004, 'Mobile Laboratory with Rapid Response Instruments for Real-Time Measurements of Urban and Regional Trace Gas and Particulate Distributions and Emission Source Characteristics', *Environmental Science & Technology,* vol. 38, no. 21, pp. 5694-703.

Kozawa, KH, Fruin, SA & Winer, AM 2009, 'Near-road air pollution impacts of goods movement in communities adjacent to the Ports of Los Angeles and Long Beach', *Atmospheric Environment,* vol. 43, no. 18, pp. 2960-70.

Kozawa, KH, Winer, AM & Fruin, SA 2012, 'Ultrafine particle size distributions near freeways: Effects of differing wind directions on exposure', *Atmospheric Environment,* vol. 63, pp. 250-60.

Krämer, U, Koch, T, Ranft, U, Ring, J & Behrendt, H 2000, 'Traffic-Related Air Pollution Is Associated with Atopy in Children Living in Urban Areas', *Epidemiology,* vol. 11, no. 1, pp. 64-70.

Krieger, N, Waterman, PD, Gryparis, A & Coull, BA 2014, 'Black carbon exposure more strongly associated with census tract poverty compared to household income among US black, white, and Latino working class adults in Boston, MA (2003–2010)', *Environmental Pollution,* vol. 190, pp. 36-42.

Lawson, SJ, Galbally, IE, Powell, JC, Keywood, MD, Molloy, SB, Cheng, M & Selleck, PW 2011, 'The effect of proximity to major roads on indoor air quality in typical Australian dwellings', *Atmospheric Environment,* vol. 45, no. 13, pp. 2252-9.

Lee, G, You, S, Ritchie, SG, Saphores, JD, Sangkapichai, M & Jayakrishnan, R 2009, 'Environmental impacts of a major freight corridor', in *Transportation Research Record*, pp. 119-28.

Levy, I, Mihele, C, Lu, G, Narayan, J & Brook, JR 2014, 'Evaluating multipollutant exposure and urban air quality: pollutant interrelationships, neighborhood variability, and nitrogen dioxide as a proxy pollutant', *Environmental Health Perspectives,* vol. 122, no. 1, pp. 65-72.

Lipfert, FW, Wyzga, RE, Baty, JD & Miller, JP 2006, 'Traffic density as a surrogate measure of environmental exposures in studies of air pollution health effects: Long-term mortality in a cohort of US veterans', *Atmospheric Environment,* vol. 40, no. 1, pp. 154-69.

Maheswaran, R & Elliott, P 2003, 'Stroke Mortality Associated With Living Near Main Roads in England and Wales: A Geographical Study', *Stroke,* vol. 34, no. 12, pp. 2776-80.

Margolis, HG, Mann, JK, Lurmann, FW, Mortimer, KM, Balmes, JR, Hammond, SK & Tager, IB 2009, 'Altered pulmonary function in children with asthma associated with highway traffic near residence', *International Journal of Environmental Health Research,* vol. 19, no. 2, pp. 139-55.

Marshall, JD 2008, 'Environmental inequality: Air pollution exposures in California's South Coast Air Basin', *Atmospheric Environment,* vol. 42, no. 21, pp. 5499-503.

Marshall, JD, Swor, KR & Nguyen, NP 2014, 'Prioritizing Environmental Justice and Equality: Diesel Emissions in Southern California', *Environmental Science & Technology,* vol. 48, no. 7, pp. 4063-8.

Morello-Frosch, R, Pastor, M & Sadd, J 2001, 'Environmental justice and Southern California's "riskscape" - The distribution of air toxics exposures and health risks among diverse communities', *Urban Affairs Review,* vol. 36, no. 4, pp. 551-78.

Nilsson, RI, Nordlinder, RG, Tagesson, C, Walles, S & Järvholm, BG 1996, 'Genotoxic effects in workers exposed to low levels of benzene from gasoline', *American Journal of Industrial Medicine,* vol. 30, no. 3, pp. 317-24.

Padró-Martínez, LT, Patton, AP, Trull, JB, Zamore, W, Brugge, D & Durant, JL 2012, 'Mobile monitoring of particle number concentration and other traffic-related air pollutants in a near-highway neighborhood over the course of a year', *Atmospheric Environment,* vol. 61, pp. 253-64.

Pakbin, P, Hudda, N, Cheung, KL, Moore, KF & Sioutas, C 2010, 'Spatial and Temporal Variability of Coarse ($PM_{10-2.5}$) Particulate Matter Concentrations in the Los Angeles Area', *Aerosol Science and Technology,* vol. 44, no. 7, pp. 514-25.

Pearce, J & Kingham, S 2008, 'Air pollution and environmental injustice in New Zealand: a national analysis', *Geoforum,* vol. 39, pp. 980-93.

Pearson, RL, Wachtel, H & Ebi, KL 2000, 'Distance-weighted traffic density in proximity to a home is a risk factor for leukemia and other childhood cancers ', *Journal of the Air & Waste Management Association,* vol. 50, no. 2, pp. 175-80.

Perera, FP, Tang, D, Wang, S, Vishnevetsky, J, Zhang, B, Diaz, D, Camann, D & Rauh, V 2012, 'Prenatal polycyclic aromatic hydrocarbon (PAH) exposure and child behavior at age 6-7 years', *Environmental Health Perspectives,* vol. 120, no. 6, pp. 921-6.

Peters, J, Theunis, J, Van Poppel, M & Berghmans, P 2013, 'Monitoring PM10 and Ultrafine Particles in Urban Environments Using Mobile Measurements', *Aerosol and Air Quality Research,* vol. 13, pp. 509-22.

Pikhart, H, Bobak, M, Kriz, B, Danova, J, Celko, MA, Prikazsky, V, Pryl, K, Briggs, D & Elliott, P 2000, 'Outdoor Air Concentrations of Nitrogen Dioxide and Sulfur Dioxide and Prevalence of Wheezing in School Children', *Epidemiology,* vol. 11, no. 2, pp. 153-60.

Ponce, NA, Hoggatt, KJ, Wilhelm, M & Ritz, B 2005, 'Preterm birth: the interaction of traffic-related air pollution with economic hardship in Los Angeles neighborhoods', *American Journal of Epidemiology,* vol. 162, no. 2, pp. 140-8.

Raaschou-Nielsen, O, Hertel, O, Thomsen, BL & Olsen, JH 2001, 'Air pollution from traffic at the residence of children with cancer', *American Journal of Epidemiology,* vol. 153, no. 5, pp. 433-43.

Ranft, U, Schikowski, T, Sugiri, D, Krutmann, J & Krämer, U 2009, 'Long-term exposure to traffic-related particulate matter impairs cognitive function in the elderly', *Environmental Research,* vol. 109, no. 8, pp. 1004-11.

Reponen, T, Grinshpun, SA, Trakumas, S, Martuzevicius, D, Wang, ZM, LeMasters, G, Lockey, JE & Biswas, P 2003, 'Concentration gradient patterns of aerosol particles near interstate highways in the Greater Cincinnati airshed', *Journal of Environmental Monitoring,* vol. 5, no. 4, pp. 557-62.

Riley, S, Wallace, J & Nair, P 2012, 'Proximity to major roadways is a risk factor for airway hyper-responsiveness in adults', *Canadian Respiratory Journal,* vol. 19, no. 2, pp. 89-95.

Roorda-Knape, M, Janssen, N, de Hartog, J, van VLiet, P, Harssema, H & Brunekreef, B 1998, 'Air pollution from traffic in city districts near major motorways', *Atmospheric Environment,* vol. 32, no. 11, pp. 1921-30.

Rowangould, GM 2013, 'A census of the US near-roadway population: Public health and environmental justice considerations', *Transportation Research Part D: Transport and Environment,* vol. 25, pp. 59-67.

Rundle, A, Hoepner, L, Hassoun, A, Oberfield, S, Freyer, G, Holmes, D, Reyes, M, Quinn, J, Camann, D, Perera, F & Whyatt, R 2012, 'Association of Childhood Obesity With Maternal Exposure to Ambient Air Polycyclic Aromatic Hydrocarbons During Pregnancy', *American Journal of Epidemiology*.

Senaratne, I & Shooter, D 2004, 'Elemental composition in source identification of brown haze in Auckland, New Zealand', *Atmospheric Environment,* vol. 38, no. 19, pp. 3049-59.

Shu, S, Yang, P & Zhu, Y 2014, 'Correlation of noise levels and particulate matter concentrations near two major freeways in Los Angeles, California', *Environmental Pollution,* vol. 193, pp. 130-7.

Sørensen, M, Andersen, ZJ, Nordsborg, RB, Jensen, SS, Lillelund, KG, Beelen, R, Schmidt, EB, Tjønneland, A, Overvad, K & Raaschou-Nielsen, O 2012, 'Road Traffic Noise and Incident Myocardial Infarction: A Prospective Cohort Study', *PLoS One,* vol. 7, no. 6, p. e39283.

Sørensen, M, Hvidberg, M, Andersen, ZJ, Nordsborg, RB, Lillelund, KG, Jakobsen, J, Tjønneland, A, Overvad, K & Raaschou-Nielsen, O 2011, 'Road traffic noise and stroke: a prospective cohort study', *European Heart Journal,* vol. 32, no. 6, pp. 737-44.

Spengler, JD, Treitman, RD, Tosteson, TD, Mage, DT & Soczek, ML 1985, 'Personal exposures to respirable particulates and implications for air pollution epidemiology', *Environmental Science & Technology,* vol. 19, no. 8, pp. 700-7.

Spira-Cohen, A, Chen, LC, Kendall, M, Lall, R & Thurston, GD 2011, 'Personal exposures to traffic-related air pollution and acute respiratory health among Bronx schoolchildren with asthma', *Environmental Health Perspectives,* vol. 119, no. 4, pp. 559-65.

Spira-Cohen, A, Chen, LC, Kendall, M, Sheesley, R & Thurston, GD 2010, 'Personal exposures to traffic-related particle pollution among children with asthma in the South Bronx, NY', *Journal of Exposure Science and Environmental Epidemiology,* vol. 20, no. 5, pp. 446-56.

Stuart, AL, Mudhasakul, S & Sriwatanapongse, W 2009, 'The Social Distribution of Neighborhood-Scale Air Pollution and Monitoring Protection', *Journal of the Air & Waste Management Association (1995),* vol. 59, no. 5, pp. 591-602.

Tian, N, Xue, J & Barzyk, TM 2013, 'Evaluating socioeconomic and racial differences in traffic-related metrics in the United States using a GIS approach', *Journal of Exposure Science and Environmental Epidemiololgy,* vol. 23, no. 2, pp. 215-22.

Tsai, D-H, Wang, J-L, Chuang, K-J & Chan, C-C 2010, 'Traffic-related air pollution and cardiovascular mortality in central Taiwan', *Science of The Total Environment,* vol. 408, no. 8, pp. 1818-23.

Vette, A, Burke, J, Norris, G, Landis, M, Batterman, S, Breen, M, Isakov, V, Lewis, T, Gilmour, MI, Kamal, A, Hammond, D, Vedantham, R, Bereznicki, S, Tian, N & Croghan, C 2013, 'The Near-Road Exposures and Effects of Urban Air Pollutants Study (NEXUS): Study design and methods', *Science of The Total Environment,* vol. 448, pp. 38-47.

Volk, HE, Lurmann, F, Penfold, B, Hertz-Picciotto, I & McConnell, R 2013, 'Traffic-related air pollution, particulate matter, and autism', *Journal of the American Medical Association: Psychiatry,* vol. 70, no. 1, pp. 71-7.

Wang, Y, Hopke, P & Utell, M 2012, 'Urban-Scale Seasonal and Spatial Variability of Ultrafine Particle Number Concentrations', *Water, Air, & Soil Pollution,* vol. 223, no. 5, pp. 2223-35.

Wilhelm, M, Ghosh, JK, Su, J, Cockburn, M, Jerrett, M & Ritz, B 2011, 'Traffic-related air toxics and preterm birth: a population-based case-control study in Los Angeles county, California', *Environmental Health,* vol. 10, no. 1, p. 89.

Wilhelm, M & Ritz, B 2003, 'Residential proximity to traffic and adverse birth outcomes in Los Angeles county, California, 1994-1996', *Environmental Health Perspectives,* vol. 111, pp. 207-16.

Wilton, E, Davy, P & Smith, J 2007, *Source identification and apportionment of PM10 and PM2.5 in Hastings and Auckland,* National Institute of Water and Atmospheric Research, Auckland.

Yazar, M, Bellander, T & Merritt, A-S 2011, 'Personal exposure to carcinogenic and toxic air pollutants in Stockholm, Sweden: A comparison over time', *Atmospheric Environment,* vol. 45, no. 17, pp. 2999-3004.

Yin, SN, Li, Q, Liu, Y, Tian, F, Du, C & Jin, C 1987, 'Occupational exposure to benzene in China', *British Journal of Industrial Medicine,* vol. 44, no. 3, pp. 192-5.

Zhang, KM, Wexler, AS, Zhu, YF, Hinds, WC & Sioutas, C 2004, 'Evolution of particle number distribution near roadways. Part II: the 'Road-to-Ambient' process', *Atmospheric Environment,* vol. 38, no. 38, pp. 6655-65.

Zhu, X, Fan, Z, Wu, X, Meng, Q, Wang, S-w, Tang, X, Ohman-Strickland, P, Georgopoulos, P, Zhang, J, Bonanno, L, Held, J & Lioy, P 2008, 'Spatial variation of volatile organic compounds in a "Hot Spot" for air pollution', *Atmospheric Environment,* vol. 42, no. 32, pp. 7329-38.

Zhu, Y, Hinds, WC, Kim, S & Sioutas, C 2002a, 'Concentration and size distribution of ultrafine particles near a major highway', *Journal of the Air and Waste Management Association,* vol. 52, no. 9, pp. 1032-42.

Zhu, Y, Hinds, WC, Shen, S & Sioutas, C 2004, 'Seasonal trends of concentration and size distributions of ultrafine particles near major highways in Los Angeles', *Aerosol Science and Technology,* vol. 38, no. 1, pp. 5 - 13.

Zhu, Y, Kuhn, T, Mayo, P & Hinds, WC 2006, 'Comparison of daytime and nighttime concentration profiles and size distributions of ultrafine particles near a major highway', *Environmental Science and Technology,* vol. 40, no. 8, pp. 2531-6.

Zhu, YF, Hinds, WC, Kim, S, Shen, S & Sioutas, C 2002b, 'Study of ultrafine particles near a major highway with heavy-duty diesel traffic', *Atmospheric Environment,* vol. 36, no. 27, pp. 4323-35.

Zidek, JV, Shaddick, G, White, R, Meloche, J & Chatfield, C 2005, 'Using a probabilistic model (pCNEM) to estimate personal exposure to air pollution', *Environmetrics,* vol. 16, no. 5, pp. 481-93.

3. Chapter Three: Air quality and resident demographics across the local study areas

Pattinson, W, Longley, I & Kingham, S 2014, 'Near-highway air quality at two socioeconomically disparate residential suburbs', under review in *International Journal of Environment and Pollution*

Abstract

This study continuously monitored key traffic pollutants at two roadside corridor and several associated setback sites in Auckland, New Zealand. Dispersion modelling was performed using The Air Pollution Model (TAPM) in order to compare monitored pollutant profiles to modelled profiles. Results show that, for both study sites, mean levels of UFPs, NO_x and CO were elevated by 41 - 64% at the roadside compared to setback sites as close as 134 m downwind. The main findings suggest that outdoor exposure along the roadside corridor is approximately 50% greater than for those living at setback distances. A GIS assessment of possible environmental exposure inequity found that 100% of census meshblock units situated within 150 metres of the highways were at the extreme end of the social deprivation scale. This work provides new understandings of exposure inequity at the fine community scale, which is novel in environmental justice research for New Zealand.

Keywords: environmental justice, ultrafine particles, NO_x, carbon monoxide, highway, traffic emissions, exposure, dispersion models, GIS, particulate matter

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3.1 Introduction

Throughout the international community of air quality research, it is widely recognised that strong exponential pollutant gradients occur away from busy traffic sources. Meta-analyses of numerous published studies have concluded that primary traffic pollutants generally remain significantly elevated above urban background levels to a distance of 100 - 300 m away (Karner et al. 2010; Zhou & Levy 2007). In many large cities, a significant number of citizens live adjacent to heavily-trafficked roadways. Some may spend decades or even their entire lives within this zone of influence, prompting the need for accurate, representative monitoring to ensure World Health Organization (WHO) air quality guidelines are not breached. The long-term risks associated with living next to busy roads are numerous. A raft of studies have reported finding an association between traffic emissions exposure and a heightened chance of developing respiratory problems, cardiovascular disease, diabetes, and particular types of cancers (Jephcote & Chen 2012; Pearson et al. 2010; Perez et al. 2013; Slezakova et al. 2013). Associations generally remain strong even after controlling for variables such as diet, weight, physical activity and ethnicity.

A recent study alongside a high-volume highway suggests people should live a minimum of 100 m away to be within emission levels considered safe for human health protection (Barros et al. 2013). Even with a roadway-to-household separation of 100 m, the study authors found that 82% of recorded nitrogen dioxide (NO_2) samples still exceeded the annual mean WHO guideline of 40 $\mu g/m^3$. The separation distance at which levels may fall within guidelines is dependent on local variations in meteorology and traffic composition, as well as the presence of buildings and/or vegetation. This makes it difficult to apply a standard land-use policy across a large city or region, when zoning land suitable for residential housing.

Elevated exposure and the associated health risks has driven the emergence of air quality research within the context of Environmental Justice (EJ), of which the key principle is to fairly treat all peoples in regard to environmental law, policies and regulation. However, due to cheaper land values, lower-income groups typically live closer to industrial emission sites and busy roads in many urban areas. By the early 1970s in the USA, countless studies had been published on the economic costs of pollution in regard to land values and human health. Naturally, this lead to work on population exposure equity and by the end of the decade, comprehensive works were reporting a positive association between relative poverty and air pollution concentrations at the national level (Asch & Seneca 1978). The research has grown from basic correlational studies through to advanced spatial regression techniques implemented within a Graphical Information System (GIS), which form the basis of most current-day analyses. These spatial models usually employ traffic volume and proximity factors as a proxy for emission concentrations, while others additionally utilise emission values generated by a dispersion model or interpolated from fixed-station monitors.

North American EJ studies have confirmed a link between lower socio-economic status and/or minority population groups, and higher pollution exposure in: Hamilton (Buzzelli & Jerrett 2004) and Toronto, Ontario (Buzzelli & Jerrett 2007), Montreal, Quebec (Sider et al. 2013), Seattle and Portland, Washington (Bae et al. 2007), Los Angeles (Houston et al. 2013; Marshall 2008; Su et al. 2009), North Carolina (Gray et al. 2013) and Florida (Gilbert & Chakraborty 2011; Grineski et al. 2012; Stuart et al. 2009). Very recently, two studies have assessed the entire United States and confirm that these exposure disparities extend to the national level (Rowangould 2013; Tian et al. 2013). Further, these analyses have been able to address the degree of exposure inequity between regions, as well as identify previously unstudied areas of EJ concern. Rowangould's (2013) study also stressed that 32% of the national population live near high-volume roads in counties for which there is no regulatory emissions monitoring. Not only are the lower social classes more exposed, they are also less protected by air monitoring sites. However, there are some exceptions; one example being New York City, where Manhattan is the most polluted, yet also the most affluent area (Ross et al. 2013).

In Europe, the situation tends to be quite different from the USA as a whole, due to the prestigious neighbourhoods of older cities being situated in the busiest zones. For Rome, Italy, Cesaroni et al. (2010) found that medium and high-income socioeconomic areas were more exposed to the higher traffic volumes than low-income areas and for Strasbourg, France, the middle class were the most exposed group (Havard et al. 2009). An analysis of the outputs produced by the European Study of Cohorts for Air Pollution Effects (ESCAPE) - a study in 14 European cities, found that pooled results for NO_2 exposure at the home address were greatest for those in the upper-income class and those with higher education (Temam et al. 2013). Yet, as to be expected, heterogeneity in exposures was reported both between and within cities.

The wide-ranging results for different areas highlight the need to assess EJ on a case-by-case basis; at national and regional levels, at the city level, and even at finer, intra-urban scales. Environmental Justice studies with regard to air quality are extremely limited for New Zealand and only two exist at the national level. Both of these were based on PM_{10} concentrations, for which domestic wood burning for home heating is the key source and is thus not a representative marker of traffic emissions. Nonetheless, they have presented some most relevant findings. Pearce & Kingham (2008) found that while the more socially deprived areas were home to the highest PM_{10} concentrations, minority groups as a whole were not disproportionately exposed. Building on this, a nationwide cohort study linking PM_{10} concentrations with all-cause mortality (in adults) found that odds increased by 20% per 10 μg/m^3 increase for Māori, but only 7% for European (Hales et al. 2010). Although minority groups may not face greater exposure, this finding provides evidence suggestive of a degree of disparate susceptibility between particular ethnicities. This is supported by the fact Māori and Pacific Island peoples suffer from disproportionately elevated rates of respiratory problems and diabetes (Cheer et al. 2002). Poor neighbourhood air quality can exacerbate such conditions, imposing an additional risk factor on local residents that may not exist if they lived elsewhere.

Using a GIS, we estimated the number of citizens living within 150 m of a major highway (> 80,000 AADT) in Auckland city to be approximately 41,000[1]. Although only roughly 2.7% of the city's population, lower land values typically result in roadside corridors being populated by the poorest and most vulnerable to elevated air toxics concentrations. At least 40% of these roadside dwellers live in South Auckland - an area predominately composed of minority and immigrant communities. Of the Census Areas Units (CAUs) immediately adjacent to South Auckland highways, 87% are Decile 9 and 10 units, which are the most socially deprived under the New Zealand Deprivation Index (Salmond et al. 2007). Of the ten current Auckland Council regulatory monitoring sites, only four are within 150 m of busy roadways (> AADT 25,000), with only one of these situated directly within a residential area (Auckland Regional Council 2005). Similar to many overseas situations, the theme for Auckland appears to be one of heightened resident susceptibility coupled with an under-representation in monitoring.

In this study we assess residential roadside corridor and setback air quality at two socioeconomically and ethnically distinct suburbs of South Auckland. This is achieved via the targeted placement of the same US EPA Federal Equivalent Method (FEM) instrumentation used at regulatory sites. The aim is to analyse observed diurnal averages both upwind and downwind from the highways, at various distances, to discover if residents live within continuously elevated concentrations of key traffic pollutants. These diurnal profiles are compared to profiles generated from vehicle emissions data run through an atmospheric dispersion model. Additionally, a comparison is made between the two

[1] Based on approximately 13,700 homes within 150 m of the edge of a main highway (> 80,000 vehicle movements per day) and an average household size of 3.0 persons. Note that an average of 3.0 persons per household pertains to data for South Auckland, where there is a higher proportion of family households and lower median income compared to Auckland city as a whole (Statistics New Zealand 2010).

suburbs to address possible environmental inequity within a relatively deprived greater region. This study is novel in that it utilises actual pollutant and meteorological observations rather than alternative variables as a proxy for emissions concentrations. Further, the dispersion modelling gives some insight into the advantages of real-time monitoring. Although limited to a small area, it provides an interesting case study and we believe it is the first of its kind for New Zealand.

3.2 Methods

3.2.1 Study areas

Five sampling sites at two residential suburbs of South Auckland, Otahuhu and Mangere Bridge (Figure 3.1), were chosen as ideal locations for comparison due to their flat terrain (0 - 23 metres), similar meteorology and relative lack of industrial emissions. The climate is warm-temperate with high humidity, but is also prone to cool overnight temperatures (< 10°C) and still mornings during winter. Both suburbs featured a 'roadside' site which was placed as close as was physically possible to the roadway, along with one or two 'setback' sites. For Otahuhu (Study Area 1, 1.5 km^2), we use the term 'setback' to describe sites located outside or just within the tail end of the expected exponential decay curve. For Mangere (Study Area 2, 1.9 km^2), the 'setback' site is such a distance from the roadside that it would be better described as a 'background' site, but is referred to as 'setback' to maintain congruity. As campaign resources were limited, the data from this site (being collected for a different study) was all that was available. Hence the study design differs from the campaign for Otahuhu.

Each of the two areas has a six-lane highway running through the centre, with the key differences being that Otahuhu saw 33% higher traffic volumes (Annual Average Daily Traffic [AADT] of 122,098 vehicles) and 35% reduced mean wind speed (2.6 m/sec) for the campaign periods (NZTA 2013a). It is worth noting that for both roads, traffic fleet composition in terms of light vs. heavy commercial vehicles, is much the same (~7.5% heavy).

Sampling took place from 1st May to 31st July, 2010 at Otahuhu and 1st to 30th April, 2011 at Mangere Bridge. An additional sampling site several kilometres north of Otahuhu was used as a control site to assess meteorology and pollutant levels between the two sampling periods (Labelled A - Control Site, Figure 4.1).

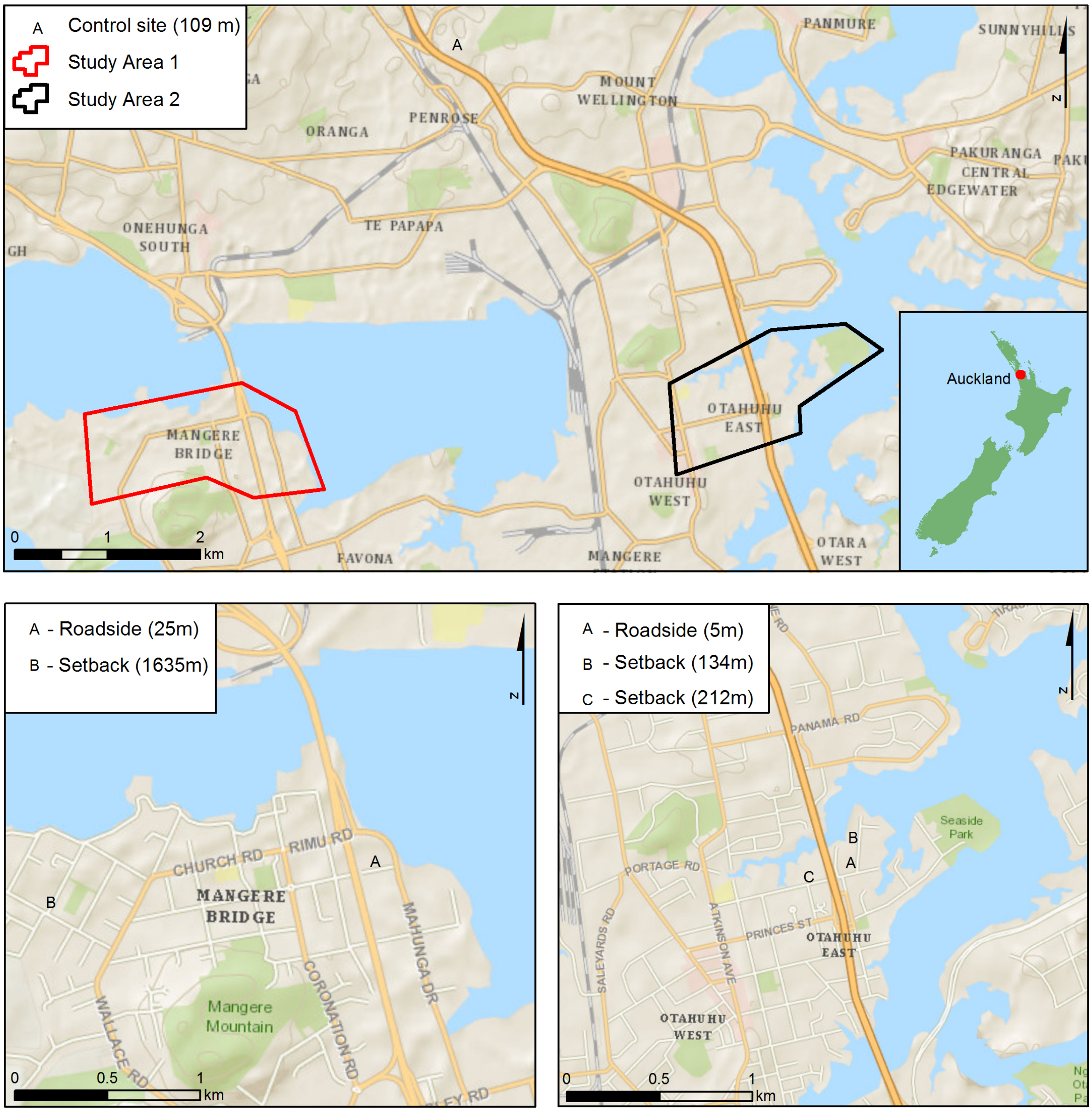

Figure 3.1 Location of study areas and sampling site layout

Otahuhu is predominately a Pacific Island community, with 52% identifying as Pacific Islander, 20% as Māori and the remainder mostly Asian (Indian). It is also one of the poorest areas of Auckland, with a median annual income of $18,000. Mangere Bridge is made up of 31% Pacific Islanders and 22% Māori, with the bulk of the remainder being European (48%). Median income is $25,000 per year and is on par with the median income for the whole of the Auckland region (Statistics New Zealand 2006).

3.2.2 Sampling regime and data estimation

Pollutants (CO, NO_x, PM_{10}) were sampled continuously at a resolution of 10 minutes for a period of three months (May - July, 2010) at Otahuhu and one month at Mangere Bridge (April 2011). For each campaign period, all instruments at all monitoring sites sampled simultaneously. Core instruments employed included Teledyne API gas analysers (CO, NO_x) and Thermo Scientific FH-61 BAMs (PM_{10}). Limited UFP concentration data were collected (TSI 3936 SMPS, TSI 3781) and some CO data were lost due to instrument failure. These missing data were predicted from NO_x and NO concentrations, respectively, using simple methods validated by previous studies (Kwasny et al. 2010; Longley et al. 2005).

Ultrafine data were estimated from linear relationships derived from 28 days of co-located Scanning Mobility Particle Sizer (SMPS) and NO_x analyser data. Following removal of marine-sized particles (> 50 nm), it was determined two distinct ratios under different wind speed categories were present. This resulted in the equations UFP=181NO_x (R^2=.86) for low wind speeds and UFP=225NO_x (R^2=.75) for winds above 2 m/s. The relationship between NO and CO was stronger still (R^2=.93). Figure 3.2 illustrates the ability of this simple method to reliably use one traffic marker as a proxy for another (NO_x for UFPs), within the parameters of the campaign periods. The relationship deteriorates in warm weather and may not be suitable for summertime observations. This is due to more rapid UFP particle coagulation (to a larger, non-ultrafine mode) and heightened photochemical reaction in NO_x (Kwasny et al. 2010).

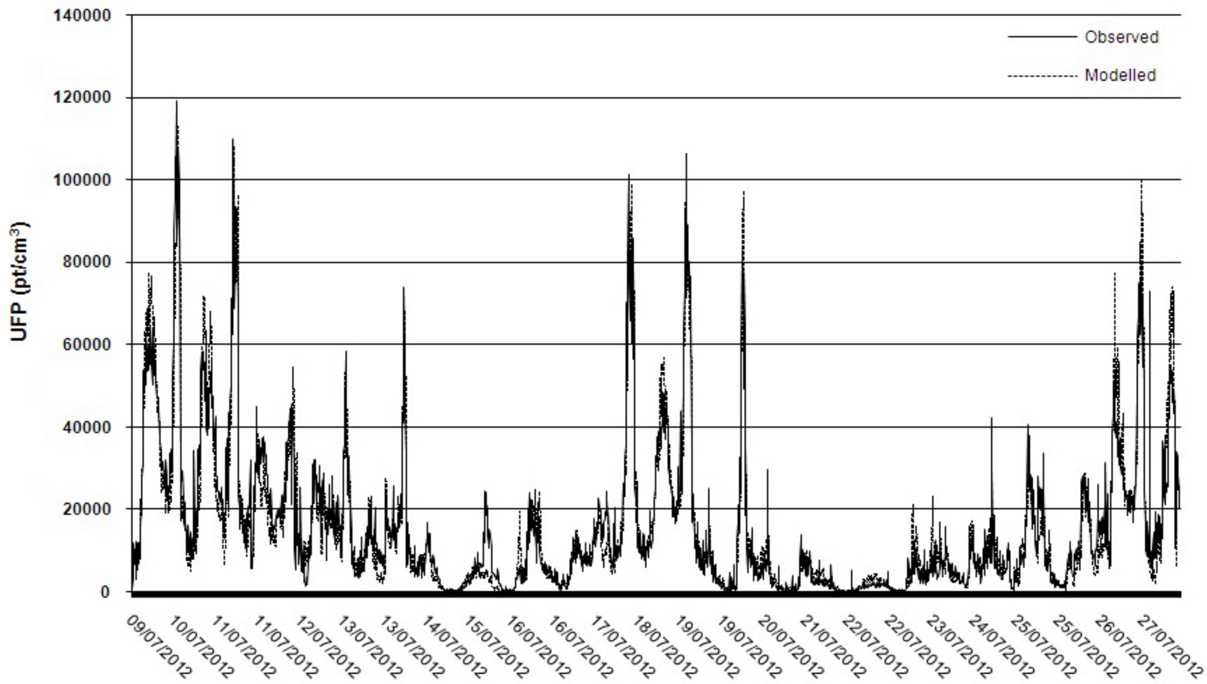

Figure 3.2 Modelled versus observed UFP concentrations over a 20-day period of July, 2012

3.2.3 Seasonality

Although the monitoring campaigns were conducted during the same seasons, due to limited availability of field equipment, they had to be completed in different years. It was important to ascertain that meteorology across the two sampling periods was not vastly different, thereby having a significant influence on pollutant concentrations. Figure 3.3 highlights the shared similarities in predominant wind direction (SW) and Table 3.1 gives mean meteorological and NO_x results. Note that overall results for the control site across the two study periods do not diverge by a great margin. Wind direction and wind speed are closely matched, with some divergence in temperature. At 109 m away, the control site is also considered a 'setback' site, explained by the low NO_x reading compared to the Otahuhu roadside site further south.

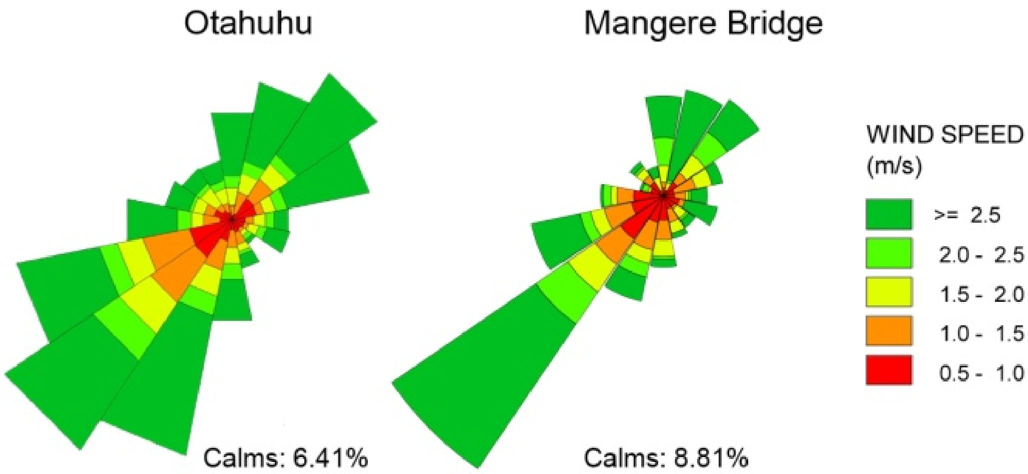

Figure 3.3 Wind roses for the two study periods from 1st May to 31st July, 2010 (Otahuhu) and 1st to 30th April, 2011 (Mangere Bridge)

Table 3.1 Mean meteorological variables and NO_x levels at control site compared with campaign roadside areas from 1st May to 31st July, 2010 (Otahuhu) and 1st to 30th April, 2011 (Mangere Bridge)

Site	Direction	Speed (m/s)	Temp °C	NO_x (µg/m^3)
Control 2010	286	2.0	12.0	72.5
Control 2011	277	1.8	15.9	58.4
Otahuhu 2010	248	2.5	12.5	122.8
Mangere 2011	203	2.0	15.9	59.1

3.2.4 Data analyses

Following quality assurance, data were collated and primarily analysed in Microsoft Excel. Dispersion modelling was conducted using The Air Pollution Model (TAPM v4.0) based on diurnal emissions profiles generated by the Vehicle Emissions Prediction Model (VEPM v5.0) - see NZTA (2013b) for details. These profiles were generated from monitored highway hourly traffic data inputs including vehicle counts, vehicle speed and fleet composition, averaged across all weekdays and weekends within the campaign periods. TAPM is a mesoscale model which includes its own advanced meteorological module and is normally applied in city-wide and regional studies; e.g. Bangkok, Thailand (Jinsart et al. 2010). However, TAPM has been successfully applied in previous work for small urban areas of New Zealand (Appelhans et al. 2010; Kingham et al. 2007). To optimise for near-field modelling, it was configured to run at the finest resolution available - a grid of 1 km^2. As the highways are situated at an approximate 15 degree angle to the west, dispersion data generated by TAPM were able to be closely matched to the same distances as the fixed stations by modelling a 5 km road length and taking the TAPM pollutant value at 1 km grid intersections measured out from the road link. In other words, the highways run diagonally through the north-south TAPM grids, allowing for results at a finer scale than one kilometre. It should be noted that all TAPM output, regardless of the road length modelled, provides output as micrograms per cubic metre, per second, per kilometre ($\mu g/m^3/s/km$). Socioeconomic analysis and subsequent map output was produced in ESRI ArcGIS version 10.1.

3.3 Results and discussion

3.3.1 Key results

For both study sites, mean levels of NO_x, CO and UFPs were elevated by 41 - 64% at the roadside compared to setback sites as close as 134 m downwind (Table 3.2). There was no overall gradient for PM_{10} at Otahuhu, with a slightly higher mean concentration at the downwind setback site and total fluctuation between the three sites being no greater than 20%. This is consistent with the expectation that the highway is not the main source of PM_{10}.

Table 3.2 Overall results from 10-minute fixed averages from 1st May to 31st July, 2010 (Otahuhu) and 1st to 30th April, 2011 (Mangere Bridge)

Site (proximity relative to highway)	Pollutant	Mean	Min.	Max.	Standard Deviation
Otahuhu Roadside (5 m east)	UFP (pt/cm^3)	23,663	277	145,202	22,301
	CO (ppm)	1.02	0.03	7.12	1.00
	NO_x (µg/m^3)	122.8	0.1	825.0	124.0
	PM_{10} (µg/m^3)	17.6	0.1	93.5	12.2
Otahuhu Setback (134 m east)	UFP	12,572	98	153,633	15,730
	CO	0.34	0.01	5.40	0.61
	NO_x	67.4	0.1	562.7	81.5
	PM_{10}	20.7	0.1	96.9	14.8
Otahuhu Setback (212 m west)	UFP	11,704	107	120,463	14,443
	CO	0.60	0.01	6.38	0.81
	NO_x	62.3	0.1	684.5	80.2
	PM_{10}	16.6	0.1	95.0	10.8
Mangere Roadside (25 m east)	UFP	11,198	200	74,870	10,514
	CO	0.48	0.05	3.89	0.52
	NO_x	59.1	0.8	425.4	59.9
	PM_{10}	16.5	0.1	47.4	8.2
Mangere Setback (1635 m west)	UFP	6,471	93	45,278	6,377
	CO	0.22	0.05	2.79	0.55
	PM_{10}	3.5	0.1	33.5	4.4

Mean roadside UFP, NO_x and CO was significantly elevated at Otahuhu; higher than Mangere Bridge by 43% (UFP, NO_x) and 56% (CO), while roadside PM_{10} was largely in agreement (6% difference). Three factors explain the substantial differences in traffic emission markers: the closer proximity of the Otahuhu roadside site (5 m compared to 25 m), the higher traffic volume (122,098 compared to 81,075) and the lower wind speeds (2.6 m/s compared to 4.0 m/s).

Figure 3.4 and Figure 3.5 illustrate mean diurnal differences in traffic emissions, with UFPs as the marker. As there was no NO_x instrument at the Mangere setback site, UFPs were chosen as the traffic marker for comparison across all five study sites. With the exception of the Mangere setback site, the shapes of the diurnal profiles also apply to NO_x. The greatest divergence between roadside and setback is during the morning traffic peak, which is gradually reduced as afternoon winds increase and traffic volumes slow into the evening (Figure 3.4). The relationship at Mangere (Figure 3.5) is less clear. This is likely due to the large distance (> 1.5 km) between sites and the fact the roads have very low traffic volumes in the setback zone. Concentrations are indicative of highly-localised sources originating mainly from private passenger vehicles.

The decay of key traffic pollutants to 40 - 60% of roadside concentrations by ~150 m is consistent with findings from studies with similar traffic volumes such as in Raleigh, North Carolina (Hagler et al. 2009) and Austin, Texas (Clements et al. 2009). Additionally, absolute mean values are also comparable e.g. 26,000 pt/cm^3 at the roadside and 16,000 pt/cm^3 at 100 m for the Raleigh study.

Most previous studies have used mobile labs to measure decay downwind from the roadway, meaning results could suffer from temporal confounding i.e. short-term changes in traffic volumes and meteorology. Secondly, the sampling campaigns are generally only several days in duration. The long-term, continuous sampling employed in our study provides a more concrete basis for determining the extent to which pollutants are elevated within the roadside corridor. Given the mean results for UFPs and NO_x at Otahuhu are closely matched (Table 3.2, Figure 3.4) under two predominately opposing wind directions (Figure 3.3), it safe to assume that the roadside corridor on the western side would be elevated to a similar degree had an extra monitoring station been available. This does not apply for Mangere Bridge, where a stronger south-westerly flow occurs (Figure 3.3).

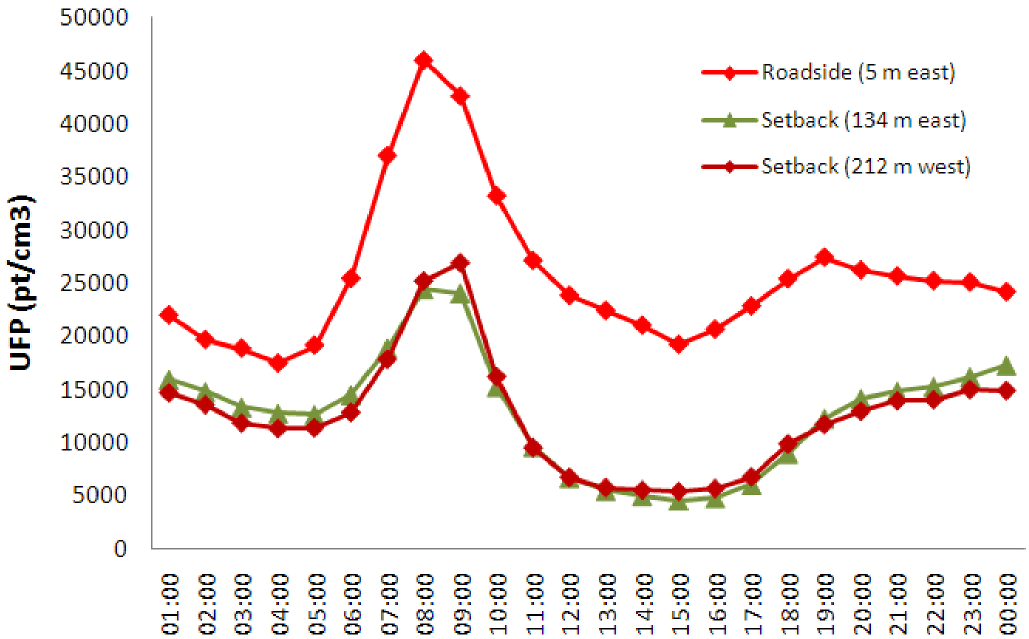

Figure 3.4 Diurnal UFP concentrations at Otahuhu from continuous 10-minute fixed-average monitoring. 1st May - 30th July, 2010

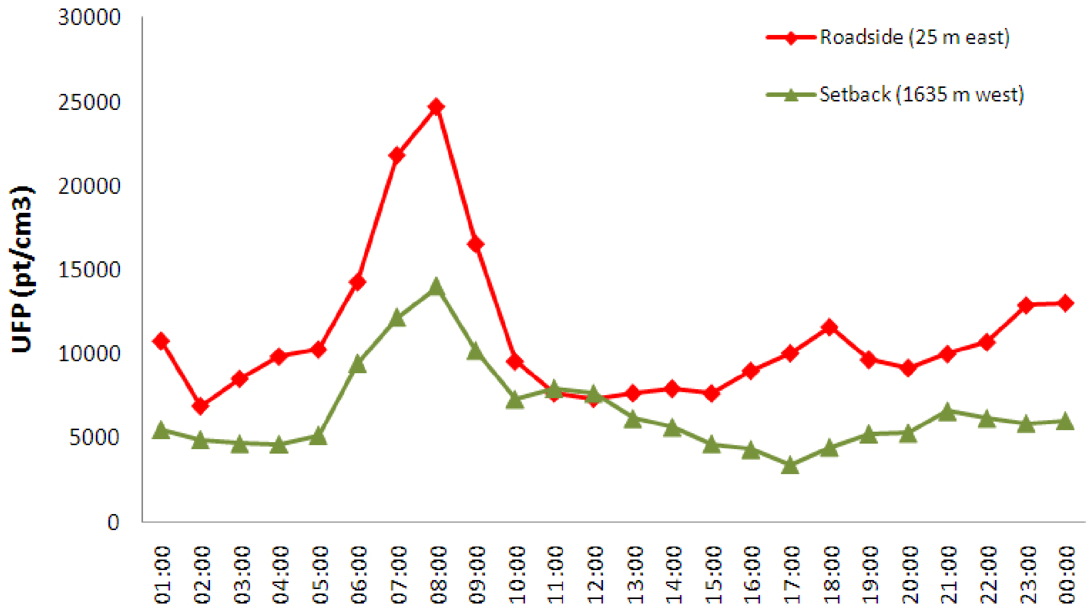

Figure 3.5 Diurnal UFP concentrations at Mangere Bridge from continuous 10-minute fixed-average monitoring. 1st to 30th April, 2011

3.3.2 Dispersion modelling

TAPM was used to compare modelled concentration profiles to monitored concentration profiles at the fixed stations. It is important to emphasise that TAPM simulates the dispersion of highway emissions only and does not take into account the influence of nearby streets and other non-highway sources. Figure 3.6 and Figure 3.7 illustrate the modelled profiles against the observed diurnal data in Otahuhu. The influence of the predominant southwest and northeast winds results in a relatively even average contribution of traffic markers to both sides of the highway. This is evident in both the observations and the modelling.

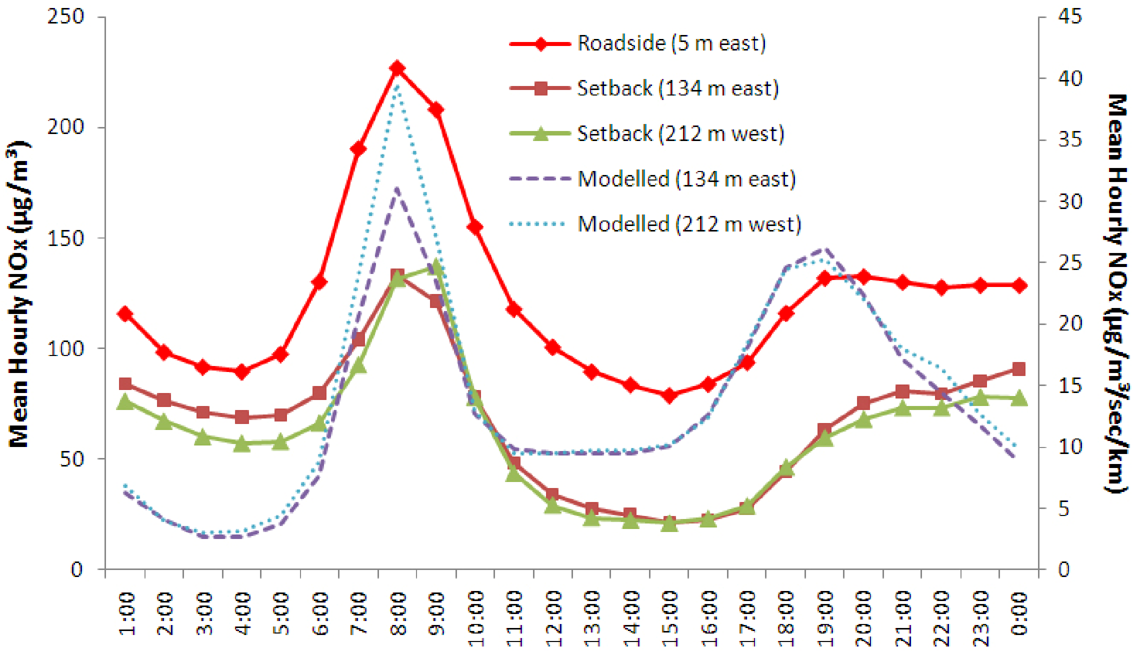

Figure 3.6 Otahuhu diurnal NO_x profiles from continuous 10-minute fixed-average monitoring and TAPM dispersion modelling. 1st May - 30th July, 2010

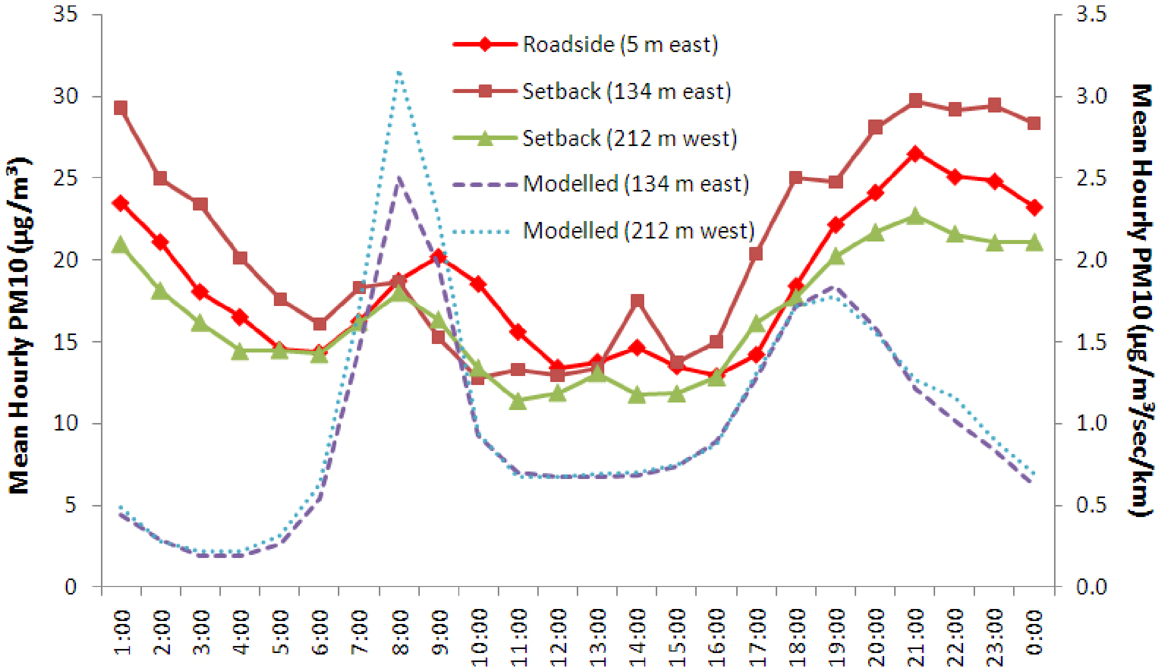

Figure 3.7 Otahuhu diurnal PM_{10} profiles from continuous 10-minute fixed-average monitoring and TAPM dispersion modelling. 1st May - 30th July, 2010

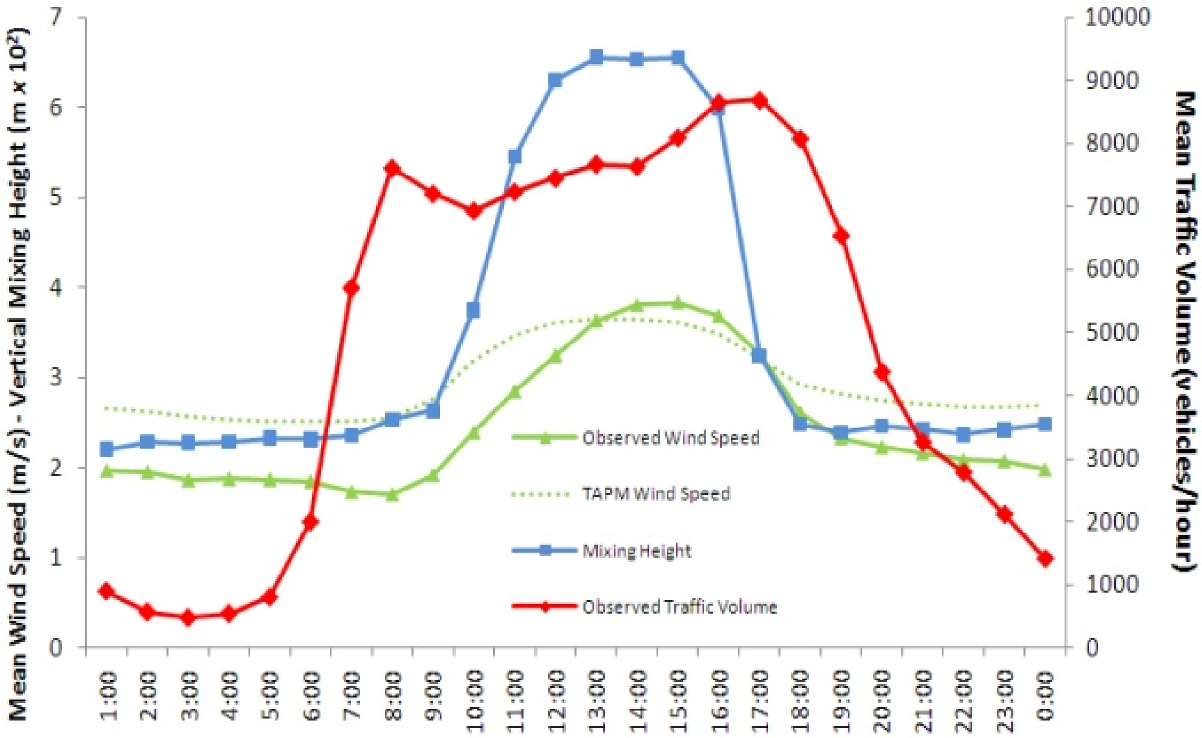

Figure 3.8 Otahuhu mixing height, wind speed and traffic volume from continuous 10-minute fixed-average monitoring and TAPM dispersion modelling. 1st May - 30th July, 2010

With the exception of PM_{10}, TAPM did a sufficient job of describing the emissions contribution from the Otahuhu highway (Figures 3.6 - 3.7). The contrast between the modelled and monitored PM_{10} profiles can be explained by the fact that PM_{10} is known to be more spatially homogenous than emitted gases such as NO_x and CO, which decay exponentially (Karner et al. 2010; Zhou & Levy 2007). Further, the primary sources of PM_{10} are background sources such as industry and home heating, with the roadway only responsible for around 10% of concentrations recorded in the immediate area. Figure 3.6 shows a strong influence of wood burning (for home heating) and industrial sources in the evening and these influences are likely associated with the less-pronounced but notable rise in CO and NO_x concentrations (Figure 3.6), respectively. Evening increases are clearly unrelated to highway traffic emissions, as observed traffic volume declines sharply from 19:00 onwards (Figure 3.8). Although traffic volume is at its highest from 14:00 - 18:00, the low afternoon concentrations are predominately shaped by increasing wind speeds and higher vertical mixing heights (Figure 3.8). These atmospheric characteristics provide sufficient dilution so that the normal bimodal profile found in many overseas studies is not present (Agudelo-Castañeda et al. 2013). Instead, CO and NO_x concentrations rise as traffic volume and wind speed decreases into the evening. This is also partly explained by the influence of background sources and the contribution from non-highway roads.

Dispersion modelling for the Mangere site performed well for the morning peak traffic period, but the afternoon profiles are in stark disagreement with the monitored profile. While the TAPM surface winds were verified against observed meteorological data, there was no means of verifying mixing layer heights. It is possible that the model greatly underestimated the mixing layer heights or that the afternoon emissions inputs were overestimated. As peak traffic volumes occurred in the afternoon rush period, the latter explanation is less likely.

This outcome from the TAPM results highlights the difficulty of purely relying on highway-source traffic emissions models and modelled concentrations. Traffic counts and composition for minor roads are rarely monitored as their influence is relatively insignificant. However, the combined influence of many residential streets in close proximity cannot be discounted, especially where there is regular queuing at intersections. Within these two study areas, traffic count and composition data is extremely limited, meaning they could only be inferred from larger roads in the area or similar roads elsewhere in the city. For health and regulatory reporting, placing monitors in as many representative locations (where people live) as possible is key to getting true results which can inform policy decisions. These data can then be used to assist and validate traffic-based models.

3.3.3 Environmental exposure inequity

The results of this study show an extreme inequity in concentrations between the two roadside communities. In the lower-income community of Otahuhu, where Pacific Island and Māori peoples make up a combined total of 72% of the population, long-term levels of key traffic pollutants are elevated by 43 - 56%; at least compared to the downwind roadside community of Mangere Bridge. The upwind side at Mangere is likely afforded typically lower concentrations. There is no question regarding the physical reasons for this environmental disparity (higher wind speeds, lower traffic volumes), but socioeconomic forces such as cheaper house and rental prices may place Otahuhu as more accessible for the lower-income classes. As the two study areas are in such close proximity, they are often lumped together in housing market research, even though Mangere Bridge is considerably wealthier. Therefore we are left to rely on measures of social deprivation to conduct comparisons. Figure 3.9 illustrates the extreme contrast in relative deprivation between the two study areas. 100% of all census meshblocks in Otahuhu are 8 - 10 (the most socially deprived), compared with only 30% at Mangere Bridge. In both study areas, all meshblocks within 150 m of the highways are 8 - 10.

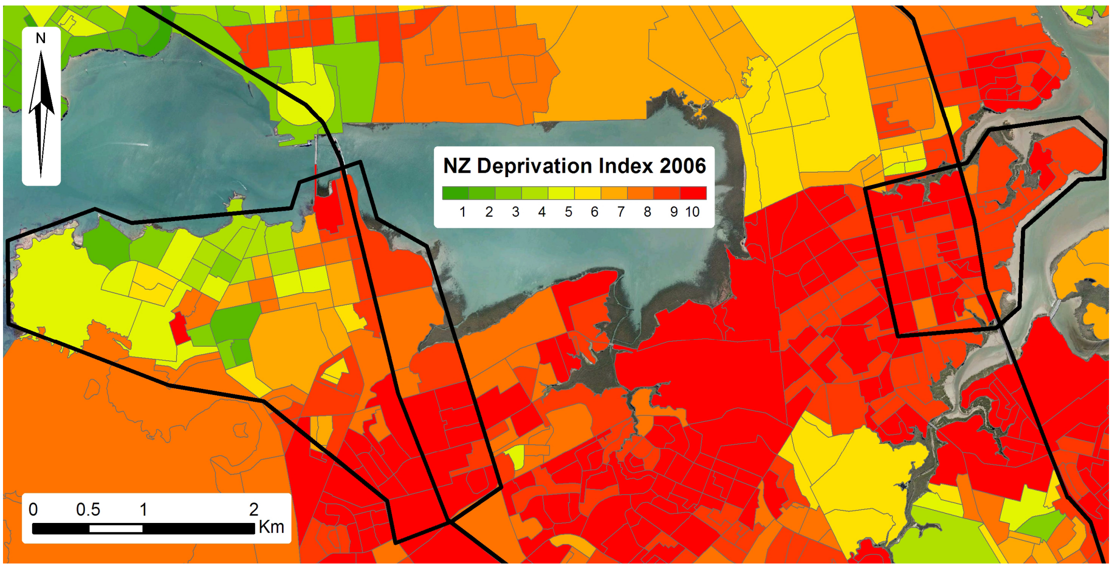

Figure 3.9 New Zealand Deprivation Index by Census Meshblock, 2006

When assessing these observations in more detail, it is clear that Europeans make up a higher percentage of residents in the least deprived areas and the lowest percentage of the most deprived areas. Figure 3.10 is almost a mirror opposite of Figure 3.9. Note that the industrial areas seen in Figure 3.10 (and Figure 3.11) have too few census respondents in them to allow for the data to be released; they must have more than 20 in each meshblock to allay privacy concerns.

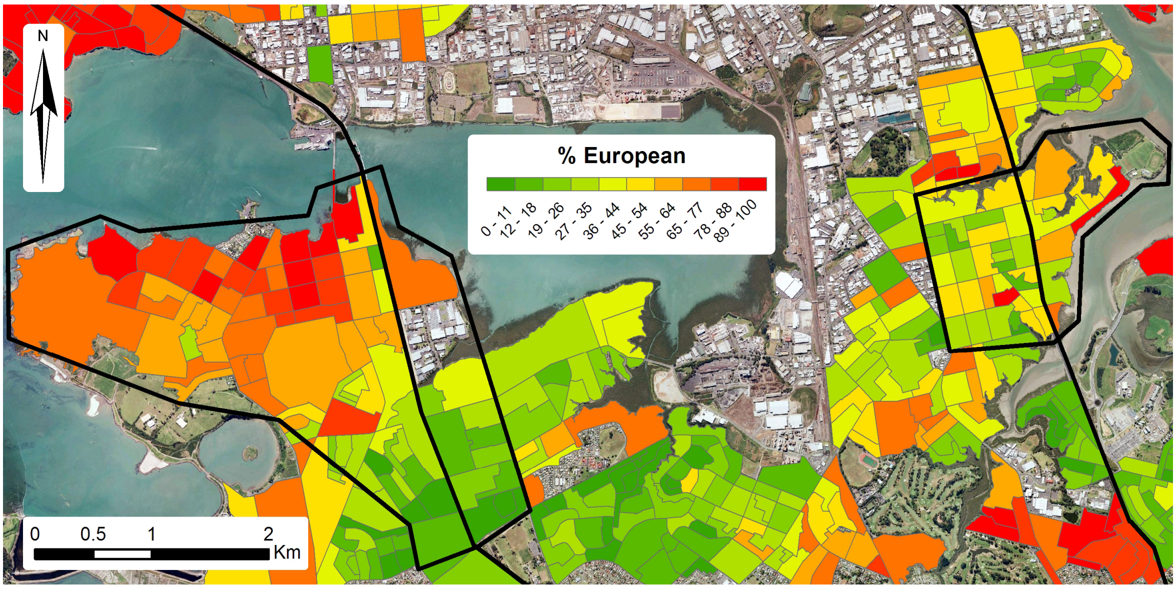

Figure 3.10 Percentage of European residents by Census Meshblock, 2006

It is an interesting finding that of all meshblocks within 150 m of the highways in both study areas, 55% consist of a population that is at least 45% European. For Māori and Pacific Peoples combined, only 45% consist of a meshblocks where these citizens represent 45% or greater of the population; the highest concentrations are between the highways (Figure 3.11). Therefore, there is a slight over-representation of Europeans living in close proximity to the highways in these specific areas. Asian ethnicities represented 24 - 50% (maximum) of the population in just 30% of roadside meshblocks. While there may be a case of environmental injustice in this area relative to social deprivation, it is a most important discovery that there does not appear to be one of ethnic injustice - at least at the community level. However, it needs to be made clear that there still could be issues of ethnic injustice within individual meshblocks (in close proximity) that do have a high number of Māori and Pacific residents - this comes down to the issue of individual susceptibility. A Europe-wide review of social inequalities in health risks from air pollutants found that lower-socioeconomic persons experienced increased detrimental effects than those from the higher classes, regardless of exposure level (Deguen & Zmirou-Navier 2010). Such effects may be further enhanced in subgroups which, like Māori and Pacific, young children, the disabled and the elderly, may be more susceptible to the regular intake of toxic fumes.

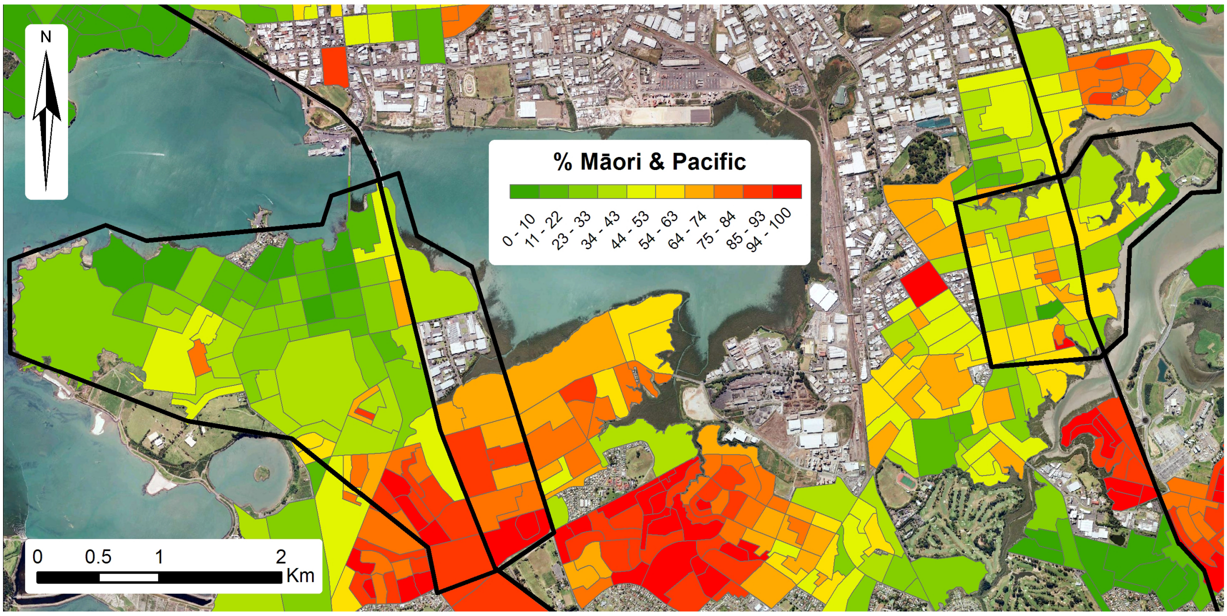

Figure 3.11 **Percentage of Māori and Pacific Island residents by Census Meshblock, 2006**

The first study to address EJ concerns in regard to air quality in New Zealand, did so for home heating emissions (PM_{10}) in Christchurch. Like our study, it found that the most deprived areas (Census Area Units) were faced with the highest levels of emissions. However, there was little evidence to suggest any ethnic gradient existed, in fact finding that areas with a high proportion of Māori had the lowest pollution levels (Pearce et al. 2006). A subsequent study, assessing only the vehicle emission contribution to PM_{10}, confirmed these key findings (Kingham et al. 2007). This has been the only local study to date which attempts to relate any exposure inequality to an element of traffic emissions, PM_{10} being a far weaker marker than alternative options such as UFPs, NO_x and CO. Although research at the national level has confirmed the previously mentioned general trends (Pearce & Kingham 2008), findings could be quite different if a primary traffic emissions marker were to be used. Similarly, the finding by Hales et al. (2010) that Māori are more susceptible to increases in PM_{10}, (than other ethnic groups) does not mean that this would hold true for all other pollutants, which have varying degrees of toxicity, affecting individuals of particular genetic makeup, differently. For example, genetic research has shown Asians and Mexican-Americans are more susceptible to benzene, a highly cancerous Volatile Organic Compound (VOC) present in petrol fumes (Nebert et al. 2002).

The main limitation of our study is that we haven't been able to address concentrations of traffic markers within the communities, further away from the highways. Passive NO_2 monitors at intersections of main arterials in the Otahuhu area showed they were, on average at the same level or slightly higher than monitors right alongside the highway (Kingham et al. 2013). This is probably explained by heavy vehicles queuing at traffic lights and then accelerating under load, whereas the highways are more free-flowing. There is most definitely a need for representative monitoring right across communities and spatial saturation work is gaining traction in the air quality arena. This can be achieved either by inexpensive, passive monitoring (aforementioned), or continuous high-resolution mobile monitoring to map the area. Several recent studies have employed the latter, with results furthering the understanding of local-neighbourhood spatial variation at finer time scales (Bassok et al. 2010; Hagler et al. 2010; Padró-Martínez et al. 2012).

3.4 Conclusions

This study has shown that long-term average pollutant concentrations within South Auckland highway corridors are substantially elevated above setback sites within relatively close proximity. While difficult to determine an exact distance from this study design, we now know that roadside concentrations of UFPs, NO_x and CO decline by 40 - 60% within 130 - 200 metres at both sides of the highway). This is consistent with studies elsewhere, which show exponential decay curves tend to level out somewhere between 100 and 300 metres downwind (Karner et al. 2010; Zhou & Levy 2007). Given the high proportion of vulnerable persons living within this elevated pollution belt, the possible associated long-term negative impacts may be significant, especially for those largely confined to their homes due to unemployment, child raising and/or disability. Further, particular ethnicities may be more susceptible to certain pollutants than others and those with pre-existing conditions are at even greater risk.

Although this study is limited to a narrow strip alongside two highways, it provides a detailed case study for the Auckland environmental justice context and is the first in New Zealand to consider multiple traffic pollutants. In line with the existing body of EJ research, we have shown that heightened exposure is related to social deprivation, but not with ethnicity. Further, we have identified that inequity can occur at the smaller spatial scales - between neighbouring communities, between meshblocks and even within meshblocks. While it isn't entirely clear from this work, the common overseas experience suggests it is primarily due to the housing market biasing exposure (that poorer people live in less desirable areas) and that minority families tend to settle in established minority areas (Deguen & Zmirou-Navier 2010).

There are few policy options that are readily applied to address exposure inequity. Demolishing homes and re-zoning land for industrial use or allocating 150 - 200 metres to reserve land would be ideal but is not at all realistic in the short-to-medium term. However, improving housing standards so that homes are less prone to infiltration by outdoor air and situating new social housing projects a minimum distance from highways, are realistic goals. It is important to continue working towards achieving clean air quality for everyone and where unavoidable, shifting the more susceptible further from key emissions sources.

Future work should expand into a more detailed exposure assessment of community air quality by including all roads where people live, including the busy arterials that have been identified as potential hotspots. Auckland and perhaps the whole of New Zealand would benefit from a complete meshblock assessment of population proximity to all major roads, possibly expanding the environmental justice investigation.

Acknowledgments

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References

Agudelo-Castañeda, DM, Teixeira, EC, Rolim, SBA, Pereira, FN & Wiegand, F 2013, 'Measurement of particle number and related pollutant concentrations in an urban area in South Brazil', *Atmospheric Environment,* vol. 70, pp. 254-62.

Appelhans, T, Sturman, A & Zawar-Rewa, P 2010, 'Modelling emission trends from non-constant time series of PM10 concentrations in Christchurch, New Zealand', *International Journal of Environment and Pollution,* vol. 43, no. 4, pp. 354-63.

Asch, P & Seneca, JJ 1978, 'Some evidence on the distribution of air quality', *Land Economics,* vol. 54, no. 3, pp. 278-97.

Auckland Regional Council 2005, *The ambient air quality monitoring network in the Auckland Region*, Auckland Regional Council, Auckland.

Bae, CHC, Sandlin, G, Bassok, A & Kim, S 2007, 'The exposure of disadvantaged populations in freeway air-pollution sheds: a case study of the Seattle and Portland regions', *Environment and Planning B: Planning and Design,* vol. 34, no. 1, pp. 154-70.

Barros, N, Fontes, T, Silva, MP & Manso, MC 2013, 'How wide should be the adjacent area to an urban motorway to prevent potential health impacts from traffic emissions?', *Transportation Research Part A: Policy and Practice,* vol. 50, pp. 113-28.

Bassok, A, Hurvitz, PM, Bae, CHC & Larson, T 2010, 'Measuring neighbourhood air pollution: The case of Seattle's international district', *Journal of Environmental Planning and Management,* vol. 53, no. 1, pp. 23-39.

Buzzelli, M & Jerrett, M 2004, 'Racial gradients of ambient air pollution exposure in Hamilton, Canada', *Environment and Planning A,* vol. 36, no. 10, pp. 1855-76.

Buzzelli, M & Jerrett, M 2007, 'Geographies of susceptibility and exposure in the city: environmental inequity of traffic-related air pollution in Toronto', *Canadian Journal of Regional Science,* vol. 30, pp. 195-210.

Cheer, T, Kearns, R & Murphy, L 2002, 'Housing policy, poverty, and culture: 'discounting' decisions among Pacific peoples in Auckland, New Zealand', *Environment and Planning C: Government and Policy,* vol. 20, no. 4, pp. 497-516.

Clements, AL, Jia, Y, Denbleyker, A, McDonald-Buller, E, Fraser, MP, Allen, DT, Collins, DR, Michel, E, Pudota, J, Sullivan, D & Zhu, Y 2009, 'Air pollutant concentrations near three Texas roadways, part II: Chemical characterization and transformation of pollutants', *Atmospheric Environment,* vol. 43, no. 30, pp. 4523-34.

Deguen, S & Zmirou-Navier, D 2010, 'Social inequalities resulting from health risks related to ambient air quality - A European review', *European Journal of Public Health* vol. 20, no. 1, pp. 27-35.

Gilbert, A & Chakraborty, J 2011, 'Using geographically weighted regression for environmental justice analysis: Cumulative cancer risks from air toxics in Florida', *Social Science Research,* vol. 40, no. 1, pp. 273-86.

Gray, SC, Edwards, SE & Miranda, ML 2013, 'Race, socioeconomic status, and air pollution exposure in North Carolina', *Environmental Research,* vol. 126, pp. 152-8.

Grineski, S, Collins, T & Chakraborty, J 2012, 'Hispanic heterogeneity and environmental injustice: intra-ethnic patterns of exposure to cancer risks from traffic-related air pollution in Miami', *Population and Environment,* vol. 35, pp. 26-44.

Hagler, GSW, Baldauf, RW, Thoma, ED, Long, TR, Snow, RF, Kinsey, JS, Oudejans, L & Gullett, BK 2009, 'Ultrafine particles near a major roadway in Raleigh, North Carolina: downwind attenuation and correlation with traffic-related pollutants', *Atmospheric Environment,* vol. 43, no. 6, pp. 1229-34.

Hagler, GSW, Thoma, ED & Baldauf, RW 2010, 'High-resolution mobile monitoring of carbon monoxide and ultrafine particle concentrations in a near-road environment', *Journal of the Air & Waste Management Association,* vol. 60, no. 3, pp. 328-36.

Hales, S, Blakely, T & Woodward, A 2010, 'Air pollution and mortality in New Zealand: cohort study', *Journal of Epidemiology and Community Health,* vol. 66, no. 5, pp. 468-73.

Havard, S, Deguen, S, Zmirou-Navier, D, Schillinger, C & Bard, D 2009, 'Traffic-related air pollution and socioeconomic status: a spatial autocorrelation study to assess environmental equity on a small-area scale', *Epidemiology,* vol. 20, no. 2, pp. 223-30

Houston, D, Li, W & Wu, J 2013, 'Disparities in exposure to automobile and truck traffic and vehicle emissions near the Los Angeles–Long Beach port complex'. American Journal of Public Health, Published online ahead of print, pp. e1-e9.

Jephcote, C & Chen, H 2012, 'Environmental injustices of children's exposure to air pollution from road-transport within the model British multicultural city of Leicester: 2000–09', *Science of The Total Environment,* vol. 414, pp. 140-51.

Jinsart, W, Sripraparkorn, C, Siems, ST, Hurley, PJ & Thepanondh, S 2010, 'Application of The Air Pollution Model (TAPM) to the urban airshed of Bangkok, Thailand', *International Journal of Environment and Pollution,* vol. 42, no. 1, pp. 68-84.

Karner, AA, Eisinger, DS & Niemeier, DA 2010, 'Near-roadway air quality: synthesizing the findings from real-world data', *Environmental Science & Technology,* vol. 44, no. 14, pp. 5334-44.

Kingham, S, Pattinson, W, Pearson, AL, Longley, ID, Campbell, M & Apparicio, P 2013, 'The use of a land use regression model to predict NO2 air pollution in two small areas of Auckland ', *Air Quality & Climate Change,* vol. 47, no. 3, pp. 40-4.

Kingham, S, Pearce, J & Zawar-Reza, P 2007, 'Driven to injustice? Environmental justice and vehicle pollution in Christchurch, New Zealand', *Transportation Research Part D-Transport and Environment,* vol. 12, no. 4, pp. 254-63.

Kwasny, F, Madl, P & Hofmann, W 2010, 'Correlation of air quality data to ultrafine particles (UFP) concentration and size distribution in ambient air', *Atmosphere,* vol. 1, no. 1, pp. 3-14.

Longley, ID, Inglis, DWF, Gallagher, MW, Williams, PI, Allan, JD & Coe, H 2005, 'Using NOx and CO monitoring data to indicate fine aerosol number concentrations and emission factors in three UK conurbations', *Atmospheric Environment,* vol. 39, no. 28, pp. 5157-69.

Marshall, JD 2008, 'Environmental inequality: Air pollution exposures in California's South Coast Air Basin', *Atmospheric Environment,* vol. 42, no. 21, pp. 5499-503.

Nebert, DW, Roe, AL, Vandale, SE, Bingham, E & Oakley, GG 2002, 'NAD(P)H:quinone oxidoreductase (NQO1) polymorphism, exposure to benzene, and predisposition to disease: a HuGE review', *Genetics in Medicine,* vol. 4, no. 2, pp. 62-70.

NZTA 2013a, *State Highway Traffic Data*, New Zealand Transport Agency, Wellington.

NZTA 2013b, *Vehicle emissions prediction model (VEPM 5.1) user guide*, New Zealand Transport Agency, Wellington.

Padró-Martínez, LT, Patton, AP, Trull, JB, Zamore, W, Brugge, D & Durant, JL 2012, 'Mobile monitoring of particle number concentration and other traffic-related air pollutants in a near-highway neighborhood over the course of a year', *Atmospheric Environment,* vol. 61, pp. 253-64.

Pearce, J & Kingham, S 2008, 'Air pollution and environmental injustice in New Zealand: a national analysis', *Geoforum,* vol. 39, pp. 980-93.

Pearce, J, Kingham, S & Zawar-Reza, P 2006, 'Every breath you take? Environmental justice and air pollution in Christchurch, New Zealand', *Environment and Planning A,* vol. 38, no. 5, pp. 919-38.

Pearson, JF, Bachireddy, C, Shyamprasad, S, Goldfine, AB & Brownstein, JS 2010, 'Association between fine particulate matter and diabetes prevalence in the U.S', *Diabetes Care,* vol. 33, no. 10, pp. 2196-201.

Perez, L, Declercq, C, Iñiguez, C, Aguilera, I, Badaloni, C, Ballester, F, Bouland, C, Chanel, O, Cirarda, F, Forastiere, F, Forsberg, B, Haluza, D, Hedlund, B, Cambra, K, Lacasaña, M, Moshammer, H, Otorepec, P, Rodríguez-Barranco, M, Medina, S & Künzli, N 2013, 'Chronic burden of near-roadway traffic pollution in 10 European cities (APHEKOM network)', *European Respiratory Journal,* vol. 42, no. 3, pp. 594 - 605.

Ross, Z, Ito, K, Johnson, S, Yee, M, Pezeshki, G, Clougherty, J, Savitz, D & Matte, T 2013, 'Spatial and temporal estimation of air pollutants in New York City: exposure assignment for use in a birth outcomes study', *Environmental Health,* vol. 12, no. 1, p. 51.

Rowangould, GM 2013, 'A census of the US near-roadway population: Public health and environmental justice considerations', *Transportation Research Part D: Transport and Environment,* vol. 25, pp. 59-67.

Salmond, C, Crampton, P & Atkinson, J 2007, *NZDep2006 Index of Deprivation*, Department of Public Health, University of Otago, Wellington.

Sider, T, Alam, A, Zukari, M, Dugum, H, Goldstein, N, Eluru, N & Hatzopoulou, M 2013, 'Land-use and socio-economics as determinants of traffic emissions and individual exposure to air pollution'. Journal of Transport Geography, Article in press.

Slezakova, K, Castro, D, Delerue–Matos, C, Alvim–Ferraz, MdC, Morais, S & Pereira, MdC 2013, 'Impact of vehicular traffic emissions on particulate-bound PAHs: Levels and associated health risks', *Atmospheric Research,* vol. 127, pp. 141-7.

Statistics New Zealand 2006, *2006 Census of Population and Dwellings*, Statistics New Zealand, Wellington.

Stuart, AL, Mudhasakul, S & Sriwatanapongse, W 2009, 'The Social Distribution of Neighborhood-Scale Air Pollution and Monitoring Protection', *Journal of the Air & Waste Management Association (1995),* vol. 59, no. 5, pp. 591-602.

Su, JG, Morello-Frosch, R, Jesdale, BM, Kyle, AD, Shamasunder, B & Jerrett, M 2009, 'An Index for Assessing Demographic Inequalities in Cumulative Environmental Hazards with Application to Los Angeles, California', *Environmental Science & Technology,* vol. 43, no. 20, pp. 7626-34.

Temam, S, Kuenzli, N, Anto, JM, Bousquet, J, Jarvis, D, Le Moual, N, Probst-Hensch, N, Sunyer, J & Jacquemin, B 2013, 'Association between socioeconomic status (SES) and air pollution exposure in Europe', *Environment and Health - Bridging South, North, East and West*, Basel, Switzerland.

Tian, N, Xue, J & Barzyk, TM 2013, 'Evaluating socioeconomic and racial differences in traffic-related metrics in the United States using a GIS approach', *Journal of Exposure Science and Environmental Epidemiololgy,* vol. 23, no. 2, pp. 215-22.

Zhou, Y & Levy, JI 2007, 'Factors influencing the spatial extent of mobile source air pollution impacts: a meta-analysis', *BMC Public Health,* vol. 7, pp. 89 - 99.

4. Chapter Four: Microspatial assessment of neighbourhood air quality

Pattinson, W, Longley, I & Kingham, S 2014, 'Using mobile monitoring to visualise diurnal variation of traffic pollutants across two near-highway neighbourhoods', *Atmospheric Environment,* vol. 94, pp. 782-92.

Abstract

It is widely accepted that concentrations of primary traffic pollutants can vary substantially across relatively small urban areas. Fixed-site monitors have been shown to be largely inadequate for representing concentrations at nearby locations, resulting in the increasing use of spatial modelling or mobile sampling methods to achieve spatial saturation. In this study, we employ the use of a simple bicycle to sample concentrations of ultrafine particles (UFPs), carbon monoxide (CO) and particulate matter (PM_{10}) at two small areas (< 2.5 km^2) in South Auckland, New Zealand. Portable instruments were mounted inside a custom-built casing at the front of the bicycle and every street within each study area was sampled in a grid-like fashion, at four times of day (07:00, 12:00, 17:00 and 22:00). Each area has a six lane highway running through its centre and the core aim was to visualise and describe spatial variability of pollutant levels about the highway, main arterials and quieter streets, at periods of contrasting meteorological and traffic conditions. A total of 20 sampling runs in each area (five at each of the four timings) were conducted. Meteorological data were logged continuously at background sites within each study area. Results show that the influence of highway traffic (UFPs, CO) was strongest during the mornings and late evenings when wind speeds were low, while for the midday and afternoon timings, concentrations were highest at the arterial and shopping zones. Concentrations of PM_{10} appeared to be strongest in the residential areas during mornings and late evenings, suggesting an influence of wood burning for home heating. For all timings combined, for all three pollutants, it appears the arterial roads featuring shops and numerous intersections with traffic lights, had a stronger influence on concentrations than the busier but freer flowing highways. This study provides not only an insight into microspatial hotspot variation across suburbs, but also how this variation shifts diurnally.

Keywords: Mobile monitoring, spatial variation, near roadway, highway community

4.1 Introduction

Traditionally, results from single or a few fixed monitoring stations have been used to inform research and policy surrounding air pollutant concentrations, across large urban areas. Concerns regarding representativeness have led to a range of monitoring strategies and spatial modelling techniques being developed to advance understandings of spatial variability. While concentrations of particulate matter (PM_{10}) can be spatially uniform across several kilometres, pollutants with a short atmospheric residency often decay substantially across the space of just a few metres. For example, a study in metropolitan Los Angeles reported strong uniformity between sites over five kilometres apart, due to similar source type and intensity (Pakbin et al. 2010). Other studies have reported strong spatial correlations yet diverging absolute concentrations, highlighting the influence of common meteorology but differing emissions sources and source strengths (Chow et al. 2002; Qadir et al. 2014; Wilson et al. 2006). Conversely, UFPs and gases such as CO tend to have relatively low background concentrations, are highly dependent on an immediate source and have a spatial extent limited to 100 - 400 metres (Zhou & Levy 2007). Sampling campaigns assessing pedestrian and cyclist exposure have reported substantial reductions (22 - 30%) in concentrations of UFPs and CO when moving several metres away from emissions sources (Berghmans et al. 2009; Kaur et al. 2005; Pattinson 2009).

To provide the greatest contrast in concentrations, traffic emission monitoring studies generally target heavily-trafficked roadways, with some stretching across multiple road types and land uses. Much of the work on highway areas has focused primarily on the decay in concentrations away from the main road, involving a series of fixed-stations or shifting mobile stations situated at various distances from the traffic source (Ash 2008; Baldauf et al. 2008; Buonanno et al. 2009; Clements et al. 2009; Gilbert et al. 2003; Gramotnev & Ristovski 2004; Hagler et al. 2009; Hitchins et al. 2000; Kimbrough et al. 2013; Reponen et al. 2003; Rodes & Holland 1981; Roorda-Knape et al. 1998; Zhu et al. 2002a; Zhu et al. 2002b). For major highways (Annual Average Daily Traffic, AADT > 100,000), long-term average concentrations of UFPs, nitrogen oxides (NO_x) and black carbon (BC) tend to be at least 50% higher within the first 50 - 100 metres than sites further from the highway (Kimbrough et al. 2013; Padró-Martínez et al. 2012). This results in significantly elevated long-term exposures for residents living within this zone of influence. In addition, these residents are exposed to particle sizes and compositions that others generally only encounter for very short periods. Due to processes involving condensation, evaporation and gas-phase nucleation, the bulk of freshly emitted particles are extremely small (< 10 nm) within the first 30 metres then grow (30 - 90 m) and shrink (> 100 m) further on (Zhang et al. 2004). Ultrafine particles are of increasing importance in epidemiological studies due to their ability to penetrate deep into the lungs and affect the cardiovascular system by means of systemic inflammation and oxidative stress (Araujo 2011; Langrish et al. 2012).

The long-term, combined impact of exposure to the mixture of toxins emitted from vehicle exhausts poses significant health risks to local populations, especially to those who are most vulnerable. While the implications for healthy persons are more limited, studies have reported an association between poor urban air and diabetes prevalence, exacerbation of asthma in young children and more rapid cognitive decline in the elderly (Evans et al. 2014; Pearson et al. 2010; Weuve et al. 2012). Subsequently, the composition of populations residing close to roadways is of key consideration in epidemiological research and is an important aspect of urban planning. Where possible, the placement of sensitive groups of individuals in the form of early childhood centres, schools, retirement homes and social housing projects next to high-emission zones should be avoided. Some researchers are now advocating for a complete separation of at least 100 m between all residential buildings and major roads (Barros et al. 2013). Considering this is impractical in most existing developed areas, there is a need to at least have representative regulatory monitoring in place and ideally, to attempt to understand the full spatial extent of impact under local conditions. A nationwide study of the USA found that 18 million people, or 32% of those living near high-volume roads, had no representative regulatory monitoring in their immediate area (Rowangould 2013). As roadside communities often consist of low-income and minority populations, there could be a similar lack of monitoring in countries like Australia and New Zealand where cities tend to built around dominating road networks, promoting unnecessary urban sprawl and potential issues of environmental injustice. Concern regarding the impact of busy roadways on communities has resulted in recent publications stressing the need for monitoring to be expanded right across communities to achieve full spatial saturation (Bassok et al. 2010; Buonocore et al. 2009; Padró-Martínez et al. 2012). With the exception of low-cost passive samplers with low temporal resolution, deploying a dense network of fixed-samplers is complex and expensive. Instead, mobile monitoring methods are becoming increasingly popular due to the relative low-cost and ability to capture data with high spatial and temporal resolutions. It also holds an advantage over spatial modelling techniques; real-time sampling is able to capture concentrations resulting from idling vehicles, traffic queuing and other factors generally not covered by simple proxy inputs like total traffic volume. Mobile monitoring techniques have predominantly been employed in studies comparing differing levels of exposure depending on the mode of transport used and/or the transport routes chosen.

These studies began with CO, ozone (O_3), nitrogen dioxide (NO_2) and volatile organic compound (VOC) sampling on bicycles and in cars in the early 1990s, followed by $PM_{2.5\text{-}10}$ in the late 1990s and then UFPs, $PM_{1.0}$, BC and polycyclic aromatic hydrocarbons (PAH) in the early 2000s, as the development of portable instrumentation permitted. Since then, numerous works have assessed intra-urban variation in concentrations across small areas utilising a customised vehicle or bicycle and pedestrian sampling has been used at the microspatial scale. With the exception of the DAPPLE project (Kaur et al. 2006), which employed a modified child's pram, pedestrian sampling has typically involved volunteers walking around with a backpack system to assess the influence of street canyons and factors such as side of pavement or proximity to roadway (Kaur et al. 2005; Zwack et al. 2011). Several pedestrian-based studies have focused their efforts around residential zones with schools, publishing concentration maps of the area (Adams et al. 2009; Buonocore et al. 2009; Levy et al. 2001). Although the timings (restricted to morning sampling) and spatial extent (< 1.5 km^2) have been limited for most of these studies, two stand out for recruiting local school pupils to sample comprehensive routes over a one-month period, resulting in concentration plots covering the majority of streets in the study area (Buonocore et al. 2009; Levy et al. 2001). Despite having a relatively low sampling resolution of 1-minute averages, both of these studies reported significant spatial and temporal variation and moderate-strong gradients away from roads with high traffic volume or a high proportion of heavy vehicles.

Due to the physical ease of sampling and the ability to carry more scientifically robust instrumentation, the bulk of mobile monitoring campaigns have used mobile labs inside vehicles. To eliminate the influence of self-pollution, a few have chosen to use electric vehicles (Hagler et al. 2010; Hu et al. 2012; Kozawa et al. 2009; Kozawa et al. 2012). As with fixed-site highway monitoring, mobile campaigns also typically focus on the highway or adjacent areas at peak, morning periods, when concentrations are highest. Some only map one road or monitor over a haphazard route, missing the variation across large parts of the study area. Only one has been identified where complete spatial saturation of the neighbourhood street network has been achieved. Bassok et al. (2010) measured BC over an approximate 800 m^2 highway corridor area of the International District of Seattle, WA, during 10 afternoon runs at a resolution of five seconds. Low-income, minority populations account for 80% of the residents and the area has disproportionately high rates (compared to the rest of Seattle) of respiratory issues. The study highlighted the importance of microscale monitoring in identifying impacts from arterial routes, potential mitigation through heavy traffic management and prohibiting new residential developments within 100 m of major roads.

Our study aimed to replicate the methodology employed by Bassok et al. (2010), but to expand it across two contrasting study areas, sampled at four times of day. Hu et al. (2009) have noted major diurnal contrasts in the spatial impact of freeway emissions and this is a very important air quality characteristic ignored by most mobile sampling regimes. Environmental setting is the key determinant of daily personal pollution exposure and for the near-highway resident, it is worth knowing the daily pattern of influence at the home location and throughout the local area. We attempt to explore this question for two nearby highway communities.

The goal of this study is to explore and describe intra-suburban (local neighbourhood) and microspatial (between streets) diurnal variation. This was done using a simple, non-polluting, bicycle-based sampling platform at a rapid logging resolution of one second. Although bicycles have been used in this fashion before (see Berghmans et al. 2009; Peters et al. 2013), this is the first time a bicycle has been used to extensively sample a complete neighbourhood street network. We also present a novel method of illustrating diurnal local-scale spatial fluctuation of pollutant concentrations that has the potential to be a simple, but visually powerful tool for use in future, community-based studies as to help explain the science to local populations and policy makers.

4.2 Methods

4.2.1 Study areas

The work presented here was part of a large observational campaign described by Longley et al. (2013). Two study sites were selected as ideal highway community case studies due to their close proximity to one another, similar topography and meteorological conditions, but contrasting traffic conditions. Study Area 1 was situated in an area of Auckland known as Otahuhu East (1.5 km^2); a community bisected by a six-lane highway with AADT of 120,000 vehicles (Figure 4.1). Study Area 2 was located in Mangere Bridge (2.5 km^2), several kilometres west of Otahuhu (Figure 4.1). Mangere Bridge is also divided by a six-lane highway but one which has 33% less traffic at around 80,000 vehicle movements per day. The percentage of heavy vehicle traffic is the same for each highway at approximately 7.5%. Both areas feature a highway over-bridge, with a single on-ramp on the western edge and an off-ramp on the eastern edge.

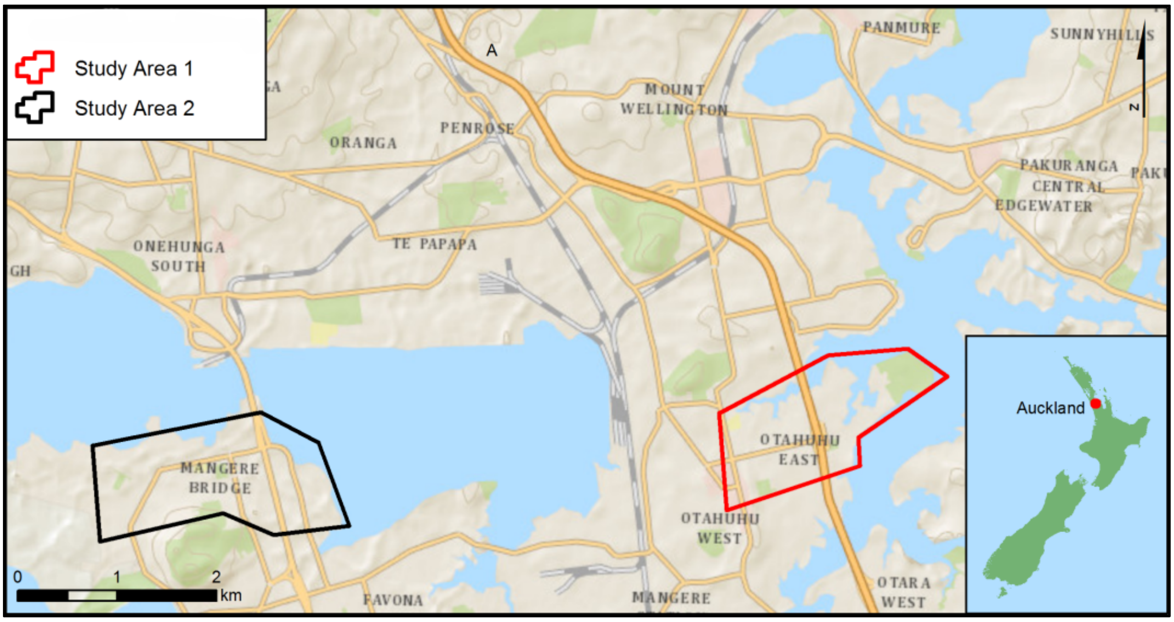

Figure 4.1 Relative location of study areas

Both areas are predominantly residential with some Business 4 and 5 zoning. Residences are largely single storey detached dwellings with garden or yard spaces. Business 4 and 5 is defined as light to medium industry, warehousing, offices and retailing activity, which does allow for discharges to air, provided Resource Consent is obtained. There are only three business (packaging and food production industries) within each study area's immediate airshed which have consent to discharge to air. The bulk of industrial use within each study area consists of low-impact offices and warehouse premises while heavier industrial activity (abattoir, steel mill, recycling plant) occurs within the general area nearby.

Elevation ranges from sea level to 23 m, with the exception of a small volcanic hill at Mangere Bridge, rising to 109 m. The climate is warm-temperate with high levels of humidity, but cool during the autumn-winter months and wood burning for home heating is commonplace. The predominant wind directions are southwest, and to a lesser extent, northeast, with wind speeds typically above 2 m/s between 10:00 and 17:00.

4.2.2 Sampling methods and context

A bicycle was instrumented with a portable ultrafine particle counter (CPC; Model 3007, TSI), a carbon monoxide sensor (Model T15n, Langan Products), a dust monitor (Model 1.107, GRIMM Aerosol Technik) and a mobile phone running custom-coded GPS logging software (Model N82, Nokia Corporation). The CO sensor sat exposed in the front pocket of the customised sampling bag and stainless steel tubing was fed into the inlets of the particle counter and dust monitor, located inside the bag's main compartment (Figure 4.2). This package had been developed for, and successfully used in a previous project (Kingham et al. 2013a).

Figure 4.2 Sampling bicycle with front-mounted instrument kit

The routes selected were designed to sample every street within the study area as well as any additional areas that were able to be accessed by bicycle, in order to achieve maximum spatial saturation. Figure 4.3 and Figure 4.4 illustrate the full spatial layout of the street grids sampled. Due to the numerous one-way-streets, it was vital to utilise a non-emitting mobile sampling platform to avoid potentially backtracking through our own emissions source. Backtracking and some route overlap was unavoidable to achieve full coverage of the area, but was kept to a minimum and the same route was travelled for every sampling session. In the case of Otahuhu (Figure 4.3), the route was extended to include a parkland track in the northeast of the study area. This provided a section of the route that was essentially free of the immediate influence of emissions sources.

A total of 20 runs of each route were sampled - five at each of four different time periods (07:00, 12:00, 17:00 & 22:00). The total length of the Otahuhu route was 15.9 km and it took an average of one hour to complete, giving an average estimated cycling speed of ~15 km/hr. Sampling took place over 17 days between 3rd of May an 14th of July, 2010. For Mangere Bridge, the total length of the route was 19 km and it took an average of 1 hour 20 minutes to complete. The route was sampled over 10 days between 18th of April and 24th of May, 2011. For most days, only one or two runs were completed, with a few days seeing three to four runs. Mobile instruments were set to sample at a resolution of one second, with the exception of the dust monitor, which was limited to sampling at six seconds.

Three fixed stations (one roadside, two background) at Otahuhu (Figure 4.3) and one roadside station at Mangere Bridge (Figure 4.4) continuously logged data at a sampling resolution of 10 minutes (fixed averages), for the entire duration of each sampling campaign. Ultrafine particles (CPC; Model 3771, TSI; SMPS; Model 3936NL85, TSI), carbon monoxide (gas filter correlation analyser; Model 300E, Teledyne API) and PM_{10} (BAM; Model FH62C14, Thermo Scientific), along with wind data (anemometer; Models A101M & W200, Vector Instruments) were recorded. The portable instruments were co-located to confirm agreement with the fixed instruments before and after each campaign period.

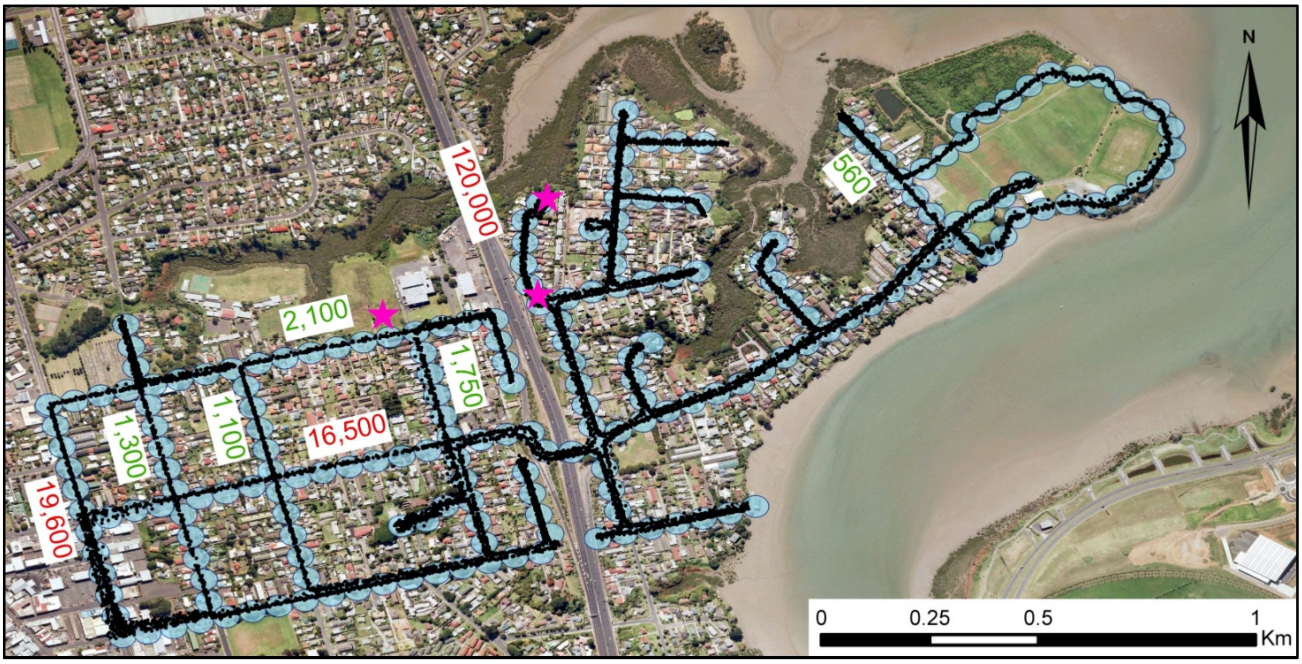

Figure 4.3 Map of Study Area 1 (Otahuhu) showing layout of sampling route (blue dots), example pooled observations (black dots), fixed monitoring stations (pink stars) and traffic volume (AADT). The main highway and two arterial routes (> than 10,000 vehicles) are labelled in red. The quieter residential streets are labelled in green

Figure 4.4 Map of Study Area 2 (Mangere Bridge) showing layout of sampling route, example pooled observations, the fixed monitoring station (pink star) and traffic volume (AADT). The main highway and two arterial routes (> than 10,000 vehicles) are labelled in red. The quieter residential streets are labelled in green

4.2.3 Analytical techniques

Each set of five runs was pooled together into their respective time period and each pooled dataset was analysed separately. Using a GIS (ArcGIS 10.1, ESRI), the sampling route was converted from line features into circular features 50 metres in diameter (Figure 4.3 & Figure 4.4). This method was previously used by Hagler et al. (2010) at 30 metre intervals and by Bassok et al. (2010), at 15.24 metre (50 feet) intervals. Fixed site monitors are often located by roadsides to identify peak pollution levels, sometimes for occupation health reasons. However, these measures are not always great indicators of population exposure as they can be biased by short term excessive peaks in very close proximity to exhaust emissions. A key challenge with mobile sampling is to therefore remove the influence of immediate contact with exhaust emissions. Hagler et al. (2010) utilised an algorithm to remove values of which followed an instance of concentrations doubling within one second, until concentrations reached <75% of the initial spike. This resulted in the removal of just 2.7% of all data. Bassok et al. (2010) standardised data by plotting the interval values as a percentage of observations within the radii of influence above the median value of a fixed station. In order to preserve concentration values for comparison with other studies, it was decided that the median value for each area of influence would be used. As the mean value is too heavily influenced by contact with high-emission vehicles, the median has also been the preferred choice in previous studies (Choi et al. 2013; Padró-Martínez et al. 2012; Peters et al. 2013). Medians were calculated for all observations within each sphere by means of a custom tool written in Python and implemented in ArcGIS. The mean number of observations for each point was 62, resulting in the elimination of the majority of excessive spikes. Contact with traffic was especially limited for the late evening runs, making it the best time of day to map true neighbourhood air quality. The influence of exhaust pipe contact is an inherent limitation of sampling on roads. Although simplistic, we feel our method is adequate for describing and explaining neighbourhood air quality.

Median concentrations were then plotted on a 3D globe (ArcGlobe 10.1, ESRI) on two axes. The horizontal axis displays concentrations using a uniform scale (a scale created from the range of values in all four datasets for each area) while the vertical axis displays concentrations based on a scale formed from that particular dataset only. This allows for viewing spatial variation across the area within the specified sampling timeframe, but also to compare fluctuations in concentrations throughout the different times of day; in other words, the diurnal variation of microspatial hotspot variability.

Finally, wind flow vectors were created for each of the eight mobile sampling periods and the 10-minute fixed-site observations were used to create plots of variation in diurnal concentrations.

4.3 Results and discussion

4.3.1 24-hourly diurnal observations

Figure 4.5 - 4.7 provide continuous fixed average hourly concentrations for Otahuhu, for the duration of the mobile sampling campaign. Figure 4.8 provides diurnal concentrations for Mangere Bridge and Figure 4.9 shows wind speed and traffic volume for both areas, while Figure 4.10 provides wind roses for each specific time period in which sampling runs were conducted.

Total mean (24-hourly) concentrations at the roadside site were 45% greater than each background site for UFPs (Figure 4.5), 56% greater than the downwind background site for CO (Figure 4.7) and only 5% higher for PM_{10} than the upwind background site (Figure 4.6). This puts the contribution of the motorway to total PM_{10} concentrations for this period, at only 5%. PM_{10} levels at the downwind background site were likely to have been affected by the close proximity to a neighbouring residential property, where open refuse burning in the afternoons and use of a wood burner almost every evening was observed. This activity is reflected by the anomalous jump in PM_{10} at around 14:00 hours and the more prominent rise into the evening than at the other two locations (Figure 4.6). Consistently higher CO concentrations at the upwind background (45% above downwind background) are probably explained by motorists using this route as a shortcut to bypass three sets of traffic lights (Figure 4.7). Although most obvious during the morning peak, when traffic was often backed near the monitoring site, vehicles were observed using this bypass at all times of day. The downwind background was completely isolated from any localised through-traffic as it was situated at the end of a one-way street (Figure 4.3 shows locations of fixed stations and traffic volumes).

General emissions trends at Mangere Bridge (Figure 4.8) were similar to Otahuhu, with very strong morning peaks for UFPs and CO, followed by a gradual rise from 17:00 onwards. There is a notable dip in the traffic signal at the roadside around 18:00 at Otahuhu (Figure 4.5) and 19:00 at Mangere Bridge (Figure 4.8) as traffic volumes decline into the evening (Figure 4.9). The background sites

(Figure 4.5 and Figure 4.7) show a smoother signal, rising into the evening as wind speeds and traffic levels drop (Figure 4.9). The strong peak observed during the morning period in both areas is due to the morning peak commuter traffic volume, cool temperatures and the lowest wind speed period of the day (Figure 4.9).

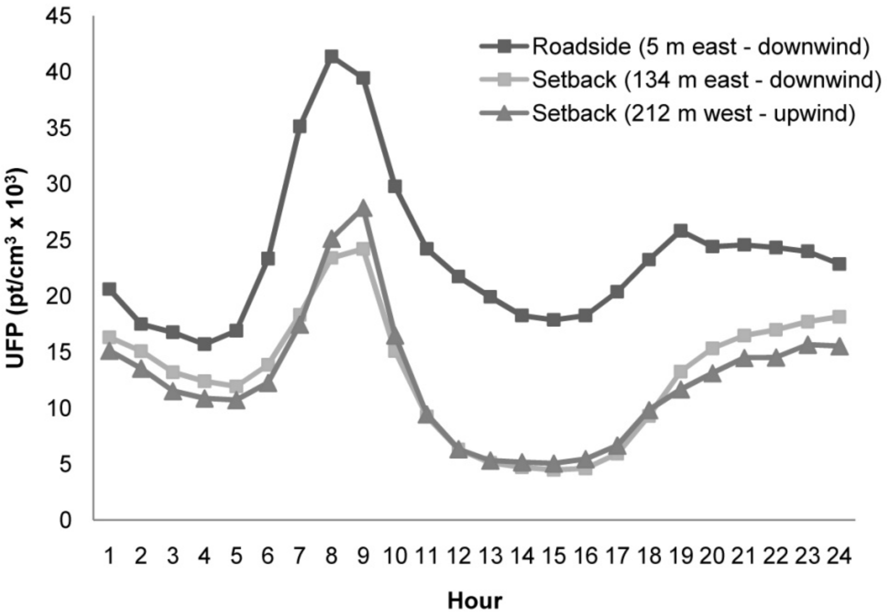

Figure 4.5 Mean diurnal UFP concentrations at Otahuhu

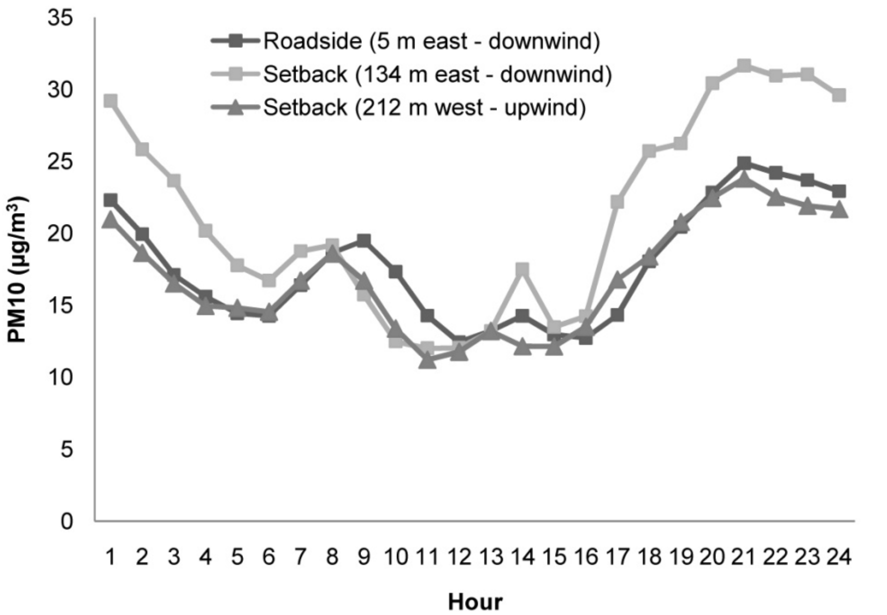

Figure 4.6 Mean diurnal PM_{10} concentrations at Otahuhu

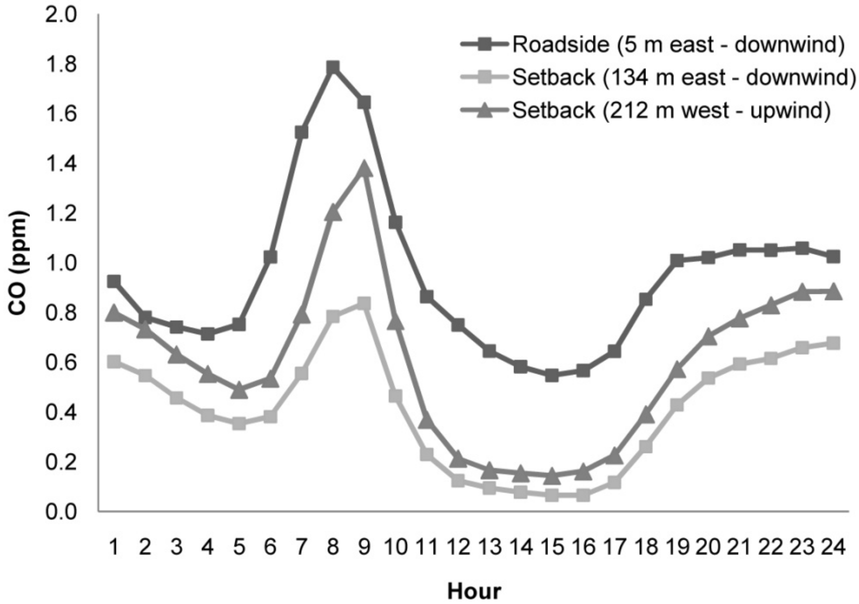

Figure 4.7 Mean diurnal CO concentrations at Otahuhu

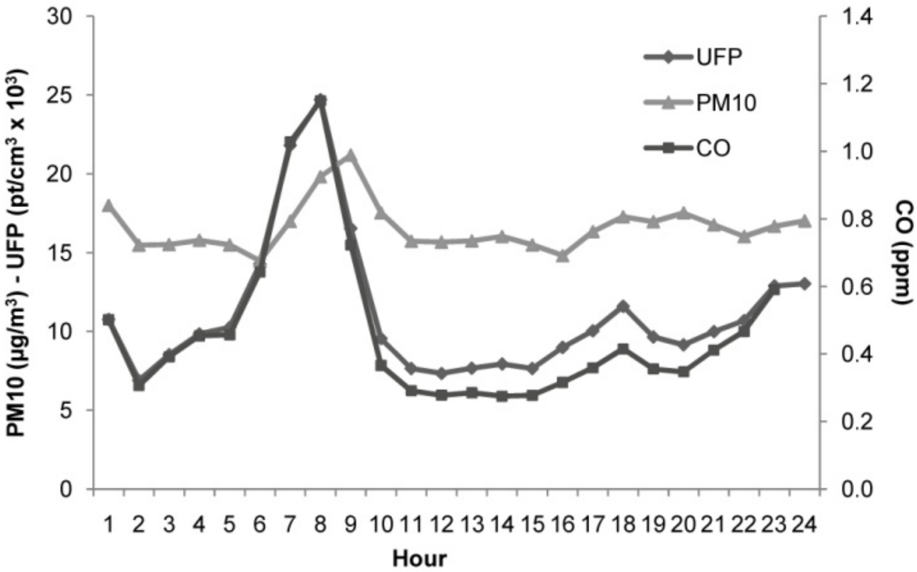

Figure 4.8 Mean diurnal UFP, PM_{10} and CO concentrations at Mangere Bridge

5.3.2 Traffic and meteorological data

Figure 4.9 illustrates mean diurnal change in traffic volume and wind speed at both study areas. Individual wind flow vectors show that for the mobile sampling periods, winds were typical of predominant meteorology in the general area. Direction is generally southwest in the morning and evening periods when speeds are lowest, compared to the higher speed, multi-directional (SW, NE) influence seen during the day (Figure 4.10).

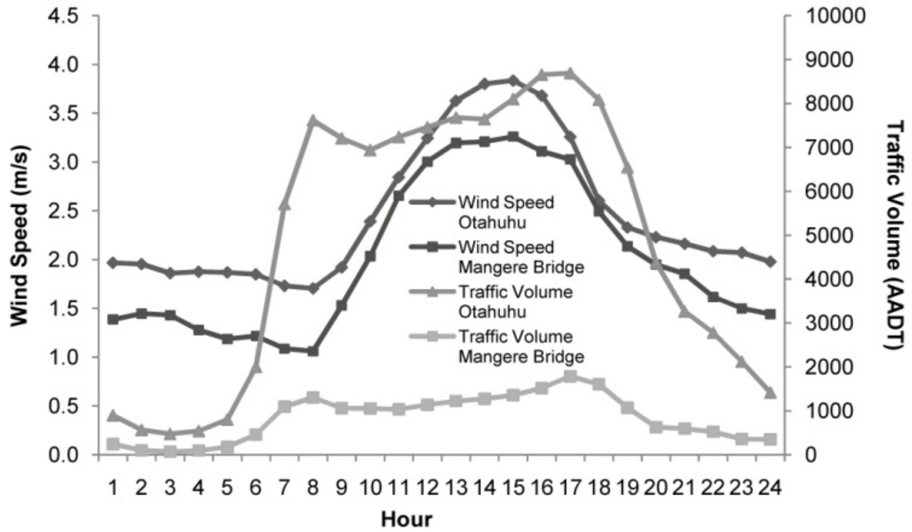

Figure 4.9 Mean diurnal traffic volume and wind speed at both study areas

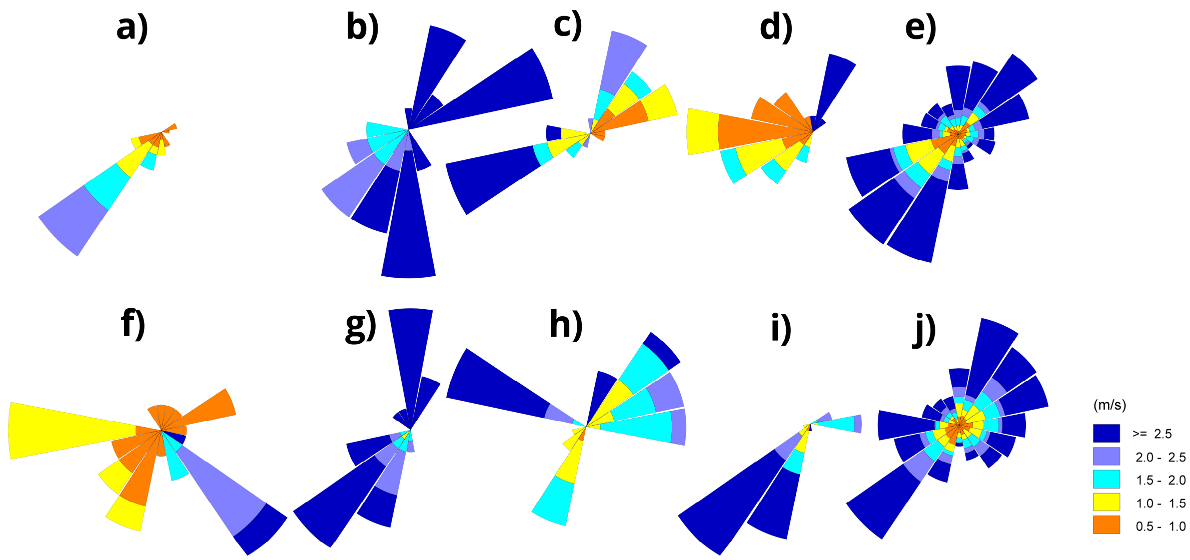

Figure 4.10 Wind roses for Otahuhu (top) and Mangere Bridge (bottom): a) morning, b) midday, c) afternoon, d) evening, e) entire campaign, f) morning, g) midday, h) afternoon, i) evening, j) entire campaign

4.3.3 Variability within and between days

10-minute fixed station measurements confirmed that there was more variability across the scheduled periods of day measured (mobile sampling), than across the days (24-hour periods) that mobile sampling took place (Table 4.1 & Table 4.2). Only CO and wind speed at Mangere Bridge were slightly less variable across days than within days. Variability is able to be compared across the data using the percent coefficient of variation (%CV) and the difference of that variability is provided in the bottom row of each table. For example, air temperature, wind speed and traffic volume at Otahuhu were 34, 26 and 77% more variable across the day than between days, respectively. This helps explain the heightened variability throughout the pollutant data (up to 26% greater for PM_{10}). However, %CV for UFP and CO, was not markedly dissimilar between the periods compared, even though a huge divergence in traffic volume %CV occurred (77 & 83%). This suggests that wind speed (dilution effects), coupled with the influence of temperature on particle and gas dynamics, plays a far stronger role on concentration variability than traffic intensity (source dynamics).

Table 4.1 Variation in roadside fixed station measurements: Otahuhu

Across Times of Day	**UFP (pt/cm^3)**	**PM_{10} (µg/m^3)**	**CO (ppm)**	**Air Temperature (°C)**	**Wind Speed (m/s)**	**Traffic Volume (vehicles/hr)**
Mean	41678	36.3	1.5	10.7	1.7	8420
SD	20126	18.1	0.8	3.8	0.7	3043
Min	22898	11.8	0.6	5.7	0.7	3198
Max	74894	62.9	2.5	14.7	2.6	10826
%CV	48	50	51	35	39	36
Across Days Sampled						**Traffic Volume (vehicles/day)**
Mean	33090	21.5	1.2	11.2	1.7	122863
SD	14314	7.9	0.6	2.6	0.5	10186
Min	9327	8.8	0.1	8.0	0.8	88086
Max	57296	43.4	2.4	15.9	3.0	132366
%CV	43	37	48	23	29	8
Difference as %	**-10**	**-26**	**-6**	**-34**	**-26**	**-77**

Table 4.2 Variation in roadside fixed station measurements: Mangere Bridge

Across Times of Day	**UFP (pt/cm^3)**	**PM_{10} (µg/m^3)**	**CO (ppm)**	**Air Temperature (°C)**	**Wind Speed (m/s)**	**Traffic Volume (vehicles/hr)**
Mean	24389	23.9	0.9	15.2	1.7	3132
SD	14867	7.7	0.5	3.0	0.7	1058
Min	12671	13.6	0.5	11.3	0.9	1320
Max	49664	34.7	1.7	19.2	2.9	3986
%CV	61	32	54	20	44	34
Across Days Sampled						**Traffic Volume (vehicles/day)**
Mean	15698	17.5	0.7	14.6	2.1	44987
SD	7790	4.9	0.4	1.9	1.0	2570
Min	6600	9.5	0.2	12.6	0.8	40959
Max	28635	24.5	1.4	17.7	4.4	48893
%CV	50	28	63	13	48	6
Difference as %	**-19**	**-14**	**16**	**-33**	**9**	**-83**

4.3.4 Mobile observations - Ultrafine particles

For Otahuhu, steep gradients were observed at the windward side of the highway during the morning and late evening periods (Figure 4.11). Concentrations decreased by ~50% over a distance of 130 m in the morning and by ~40% in the evening, reaching background levels by 650 and 615 m respectively. Wind direction was confined to westerlies. This is comparable to the difference between the roadside fixed-station and the downwind background station (separation of 129 m), which saw decays for 10-minute fixed averaged concentrations for the same time periods of 51% and 46%.

During the day, when wind directions were split between southwest and northwest, no clear gradient was found for either side of the motorway. However, the difference between the fixed stations was even stronger, with a reduction of 73% (afternoon) - 78% (midday). From approximately 12:00 to 18:00, wind speeds are typically more than double the morning and evening rates (Figure 4.9), providing rapid dispersion. Given the roadside fixed-station is situated just 5 m from the highway and the bicycle was only ever as close as 35 - 50 m, we can expect to see more intensive particle loss within the first few metres under these conditions, than further back from the road. Secondly, the Lagrangian nature of mobile sampling raises an important limitation - the likelihood of decreased intake of particles into the steel tubing under higher winds, especially under cross-winds. Despite this limitation, the mobile plots still largely represent the wider spatial differences shown by other work in the same geographical area using fixed passive NO_2 samplers (Kingham et al. 2013b). A strong gradient exists about the highway area but the highest NO_2 concentrations were recorded at the western edge of the study area where traffic volume is six-fold lower. This road is populated with retail stores and small industry and it is likely that the influence of local traffic congestion, coupled with street canyon effects, are playing a key role in elevating concentrations. This is clearly depicted in Figure 4.11b (midday) and 4.11c (afternoon).

Overall, the plots are able to illustrate the shifting influence of source strength throughout the day. Although concentrations at the main arterial are relatively stable at all four time periods, the extreme signal from the highway largely drowns out the influence of other roads during the morning and late evening. Peak morning highway concentrations are two to four times higher than concentrations at any other time of day across the entire study area (see X Axis, Figure 4.11). This is also confirmed to be twice as high at the fixed roadside site (Figure 4.5). Given the wider spatial extent during periods of lighter winds, the greatest order of magnitude in diurnal change is expected to be in the background zones.

At Mangere Bridge, similar diurnal trends are evident with high concentrations across the whole study area in the morning and very low concentrations away from main roadways for the rest of the day (Figure 4.12). Again, the influence of the highway is only evident in the morning and, to a lesser extent, the evening, with stronger signals about the village shopping area (350 m west of overbridge) during the day. Wind characteristics for these periods differ to Otahuhu, with more of a northeast origin, resulting in a wider spatial extent in the mornings to the west (50% reduction at ~250 m) than the east (50% reduction at ~200 m).

Diurnal variation in spatial extent has been observed by several fixed-site studies (Fuller et al. 2012; Kimbrough et al. 2013; Zhu et al. 2006) and is also evident from our stationary data. The margin of difference between roadside and background concentrations narrows substantially late at night and does not start to diverge until traffic volumes and wind speeds start to pick up from ~5:30 am onwards (Figure 4.5). This is characteristic of lower and more consistent wind speeds (Figure 4.9 and 4.10), low atmospheric mixing heights and cooler temperatures.

Hu et al. (2009) conducted one of the few studies that captured this variation using a mobile platform (electric vehicle), downwind of the I-10 freeway (AADT ~165,000) in Santa Monica, CA. During winter pre-sunrise hours, the extent of influence was as wide as 2.6 km and 500 m at night, dropping to 300 m during the day. The widest spatial extents observed in our study were similarly observed in the mornings and late evenings and are clearly visible in Figure 4.11a, 4.11d and 4.12a. The morning runs in Otahuhu commenced right on the cusp of sunrise.

In terms of highway traffic volume and, to a lesser extent, the methods adopted, one of the most comparable studies to our Otahuhu study occurred downwind of the I-440 (AADT ~125,000) in Raleigh, NC (Baldauf et al. 2008; Hagler et al. 2009). However, it was conducted during the summer (compared to our wintertime study) when faster decay occurs. They approximated the downwind gradient within the first 100 m to be 8% per 10 metres and at 300 m, concentrations were close to those 50 m upwind (Hagler et al. 2009).

For arterial roads, our findings are in agreement with a study along a main road (AADT 18,800) in Boston, MA. The bulk of concentrations along and adjacent to this road ranged between 24,000 and 75,100 pt/cm^3 (Buonocore et al. 2009). For the arterials in Otahuhu (AADT 16,500, AADT 19,600 -

Figure 3), concentrations typically ranged between 30 - 70,000 pt/cm^3 at all times of day, being slightly higher in the mornings.

Differences in traffic volumes, fleet composition, seasonal influences and variation in traffic trends across seasons, make it difficult to make international comparisons. For example, mid-winter UFP concentrations in a street canyon in the centre of Helsinki, Finland were found to be as high as 800,000 pt/cm^3 (Pirjola et al. 2012) and wintertime concentrations can be more than double summertime levels (Kozawa et al. 2012).

The most extensive community mobile monitoring study to date took place within a 2.3 km^2 area about a freeway (AADT 150,000) in Somerville, MA. A route of 15.4 km was driven five or six times per day over 55 days, covering both pre and post-sunrise hours across all four seasons (Padró-Martínez et al. 2012). Decay gradients were sharper than those found in our study - 100 - 150 m on the southwest side and ~400 m on the northwest side. As the predominant wind direction was almost parallel to the freeway, local street traffic on the northwest side may have played a role in the weaker gradient observed. Similar to our study, Padró-Martínez et al. (2012) also observed a lack of gradient downwind of the freeway later in the morning and midday periods as wind speed increased. Much of the analysis in the Somerville study involved using mobile data binned by proximity to highway. Concentrations within the 0 - 50 m bin were found to be 1.5 times higher than 100 - 150 m downwind and 200 - 450 m upwind. If we had adopted the same approach, it is plausible that the lack of gradient during the high-wind, daytime would have evened out the influence of the extreme gradients seen during cool, still mornings and evenings. Our fixed-sampler data supports this assumption, with our roadside station also being higher by a factor of 1.5 than both our upwind (212 m) and downwind (134 m) station.

Only two studies have employed a bicycle sampling platform to extensively map neighbourhood concentrations and both took place in Belgium. The first was in Mol, Flanders, a small town with a low population of 33,000 (Berghmans et al. 2009). Two routes, one within an inner-city residential area and one within a semi-industrial rural area, were compared. Like our study, the authors also noted high concentrations along a main arterial (AADT 15,200) and within shopping zones, as well as higher median concentrations during the day. Raw concentrations were reported as being as high as 500,000 pt/cm^3 in the semi-rural area - 60% higher than peak concentrations in the inner-city zone. This was likely attributable to the combined influence of heavy-vehicle (truck) traffic and very fine dust from construction activities in the area. The second study compared a route through Antwerp with another route through Mol (Peters et al. 2013). Median concentrations in the considerably larger city of Antwerp (pop. 480,700) did not exceed 50,000 pt/cm^3. Busier streets were comparable to quieter streets, an interesting finding related to the presence of segregated cycleways on the busiest roads and more congestion on the lesser-trafficked roads.

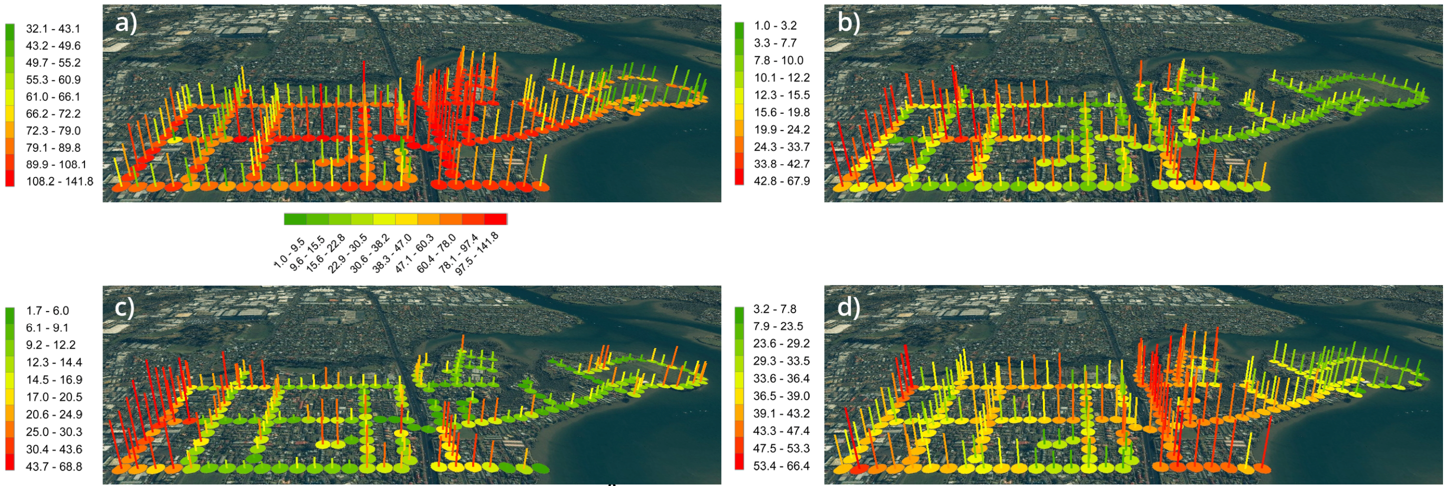

Figure 4.11 Median UFP concentrations (pt/cm^3) for Otahuhu: a) early morning b) midday c) late afternoon and d) late evening, visualised on two scales. The Y-scale (both height and colour of the vertical bars) spans the range concentrations measured at each time of day (hence colours and heights on the Y-axis are re-scaled for each of the four maps). The single X-scale, represented by the circular dots on the flat surface (the X-axis or 2D surface) of all four maps, spans the range of concentrations measured across all four time periods combined.

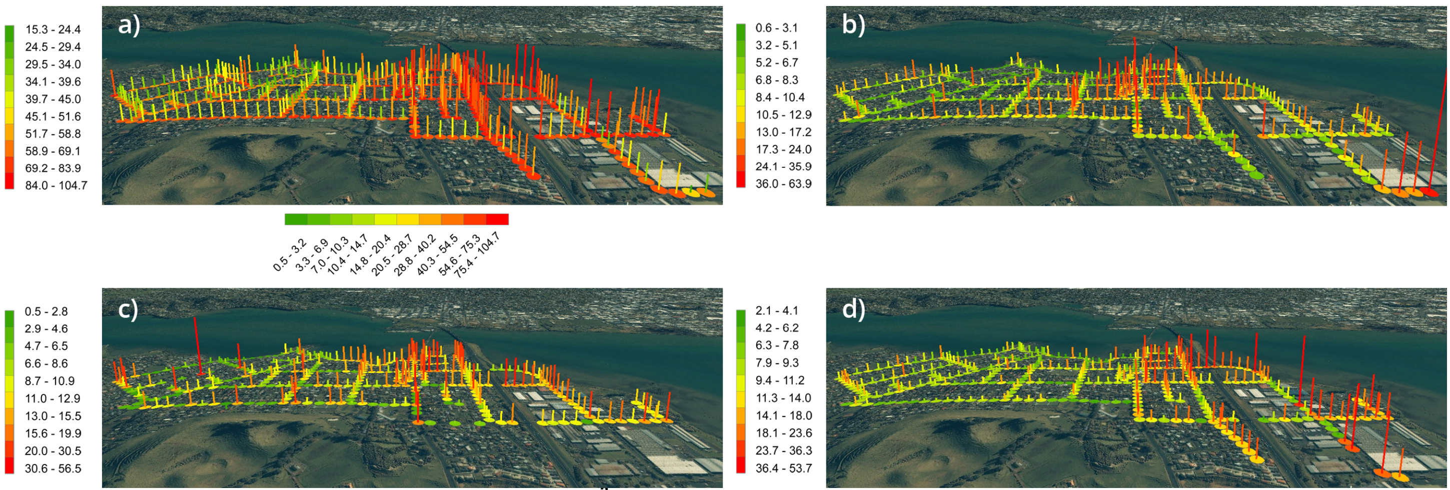

Figure 4.12 Median UFP concentrations (pt/cm^3) for Mangere Bridge: a) early morning b) midday c) late afternoon and d) late evening

5.3.5 Mobile observations - Particulate matter (PM_{10})

Figure 4.6 and 4.8 illustrate diurnal change in PM_{10} concentrations for both areas. There is no clear emissions signal from the highway in either area, but there is evidence of heavy vehicle influence at the arterial routes during the midday (Mangere - Figure 4.14b) and afternoon periods (Otahuhu - Figure 4.13c). Although no traffic composition data exists for these roads, observations made during the field campaigns can confirm a strong presence of heavy vehicles (AADT 12,500 - Figure 4.4) and heavy vehicle congestion at these times (AADT 16,500 and 19,500 - Figure 4.3). For both areas the lowest concentrations were observed during the midday period, which was confirmed by the fixed-station measurements (Figure 4.6 and 4.8). The highest levels of PM_{10} occurred during the late evening period (Otahuhu) and early morning period (Mangere). While concentrations were fairly spatially homogenous across Otahuhu, uniformity was confined to the residential zone (west of highway) at Mangere Bridge. This suggests that the main source for both areas is residential wood burning.

Fixed-site monitoring at Otahuhu during the day showed a decrease of 15 - 20% between downwind stations and an increase of 15% in the evenings. Continuous long-term monitoring (five months) reported the overall contribution of the highway to PM_{10} emissions to be in the order of 10% (Longley et al. 2013) and a contribution of 5% was noted for period of sampling in the current study. Thus the influence of the motorway is slight and the fixed-sites confirm the general lack of spatial variability. Peters et al. (2013) also found a general lack of spatial contrast, similarly, most variable between very busy streets and quiet background streets. Our PM_{10} charts are best viewed as spatial variation over and above that of the general background plume.

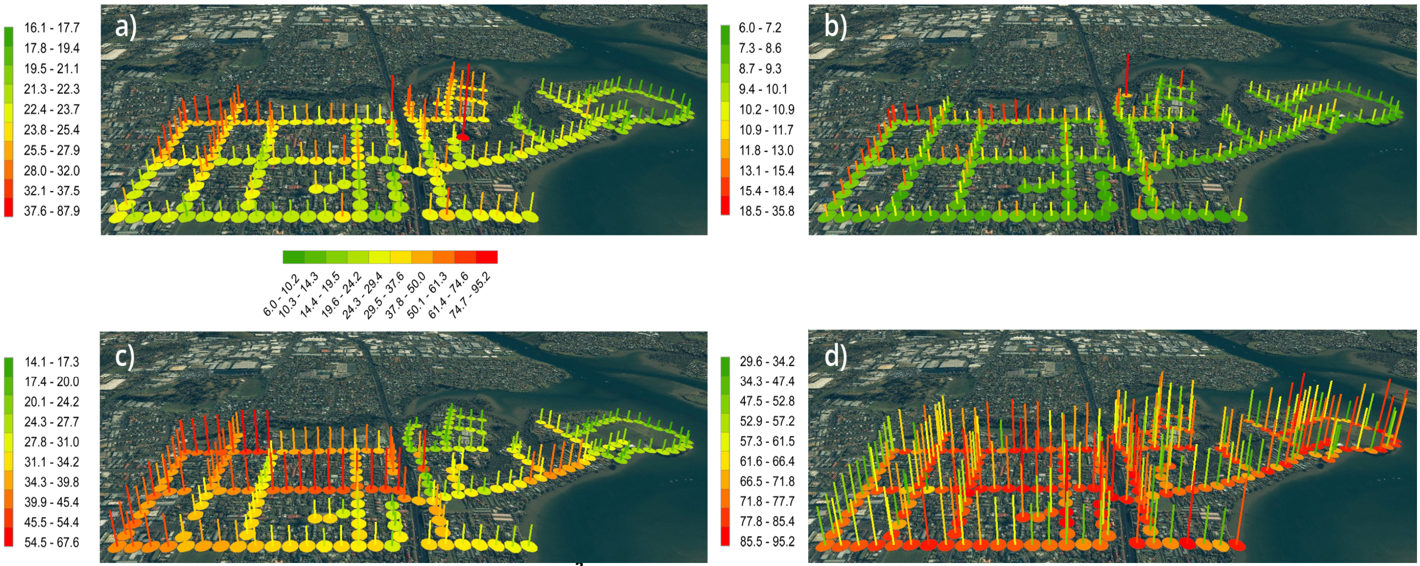

Figure 4.13 Median PM_{10} concentrations (µg/m^3) for Otahuhu: a) early morning b) midday c) late afternoon and d) late evening

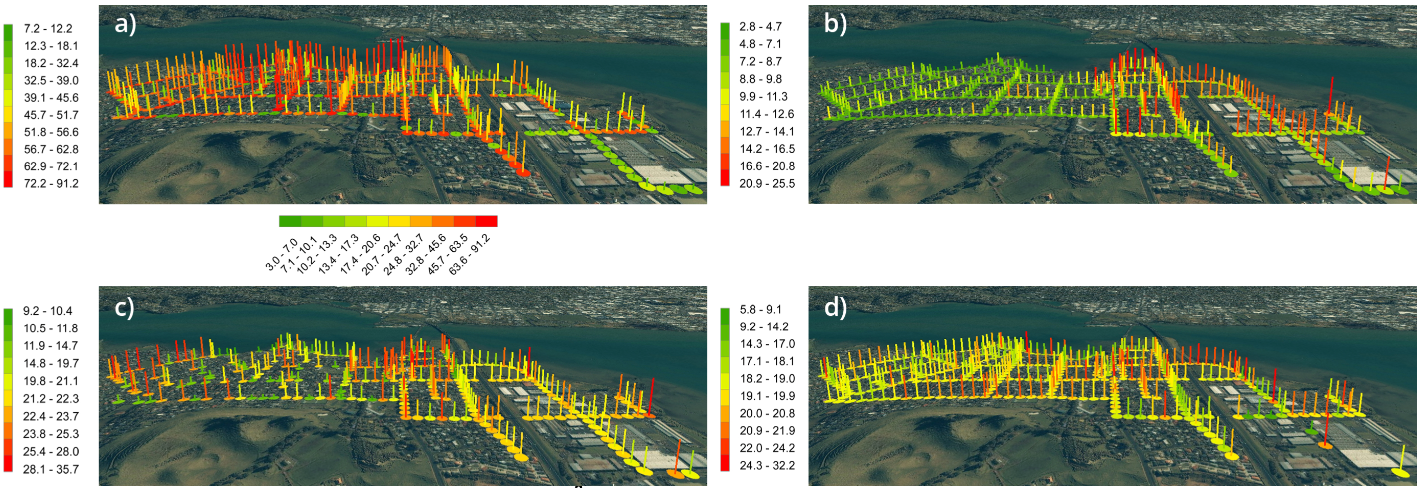

Figure 4.14 Median PM_{10} concentrations (µg/m^3) for Mangere Bridge: a) early morning b) midday c) late afternoon and d) late evening

4.3.6 Mobile observations - Carbon monoxide

Spatial patterns for CO are very similar to PM_{10}, with high concentrations and a high degree of spatial homogeneity at night for Otahuhu (west of the highway, Figure 4.15d) and during the morning for Mangere (Figure 4.16a, Figure 4.10). Considering these emissions signals were strongest within residential areas, domestic wood burning is likely to be the common source. Although also a source of UFPs, the particle size distribution of wood smoke has a much larger size mode, resulting in a significantly higher ratio of PM_{10} mass to ultrafine particle count than for tailpipe emissions. Thus PM_{10} is poorly correlated with UFPs (Boogaard et al. 2010).

With the exception of mornings in Otahuhu, there does not appear to be an obvious gradient away from either highway. However, there is a clear influence of traffic about the Otahuhu arterials (Figures 4.15b, c) and the Mangere Bridge (Figure 4.16b, c) shopping area during the midday and afternoon periods. Fixed-stations at Otahuhu showed the downwind gradient across 134 m to be 50 - 80% during the day, decreasing to 35% at night. The long-term mean difference was 61%.

Due to the normal range of CO concentrations being extremely low relative to the sensitivity of available instrumentation, and the sporadic nature of extreme spikes when encountering vehicles, it is perhaps less suitable than UFPs, NO_x or BC for this type of spatial exploration.

The main understandings gained from this mobile spatial CO dataset are similar to those reported by Hagler et al. (2010) in Durham, NC. While some decay is evident (Figure 4.15a) under downwind conditions, many extreme fluctuations occur throughout the neighbourhood. Under low wind speed conditions, spatial diversity can diminish substantially (Figure 4.15d). Hagler et al. (2010) reported a general lack of spatial attenuation throughout their study area, with median near-highway concentrations being only 20% higher than background levels. Choi et al. (2013) also noted a lack of variation within their study area and the Raleigh, NC study likewise reported an area of extent during the morning peak but no difference between roadside and background later in the day (Baldauf et al. 2008).

For our study areas, it appears that the main highway is not the main source of CO. Rather, the local street network traffic has a dominant influence during the day and domestic burning at night/early morning. Kittelson et al. (2004) explain that CO emissions factors are in fact lower for highway traffic than for street traffic due to the highest emissions occurring under heavy acceleration, and the stop-go nature of street level driving. This is also reflected in our fixed-site data, with the upwind background site being 45% higher than downwind background, positioned near a corner intersection that vehicles accelerate away from (Figure 4.3).

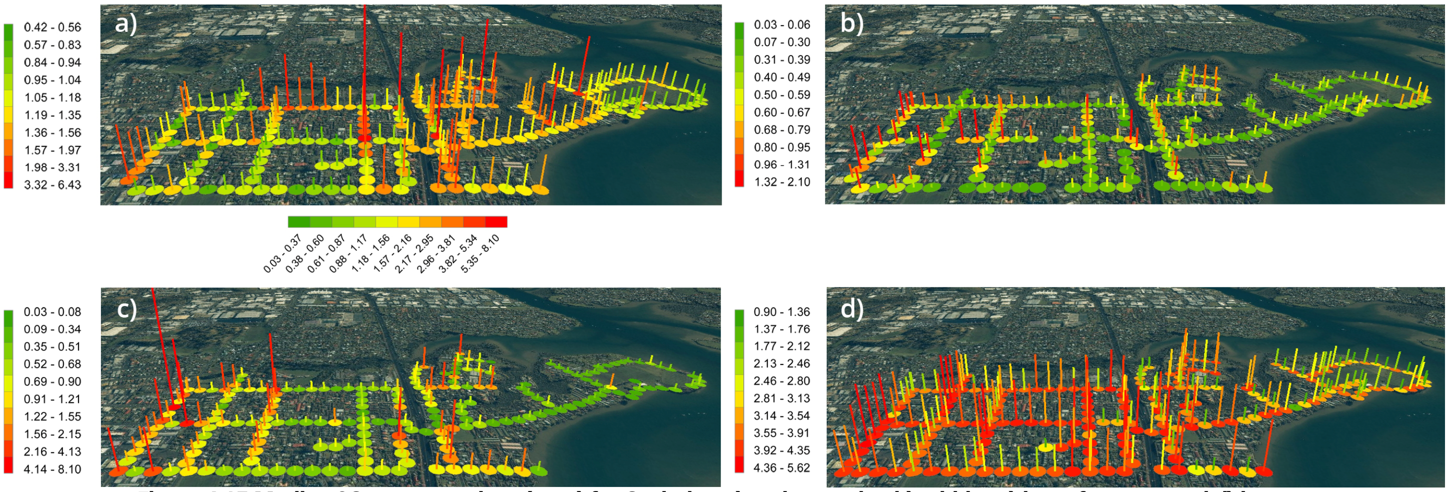

Figure 4.15 Median CO concentrations (ppm) for Otahuhu: a) early morning b) midday c) late afternoon and d) late evening

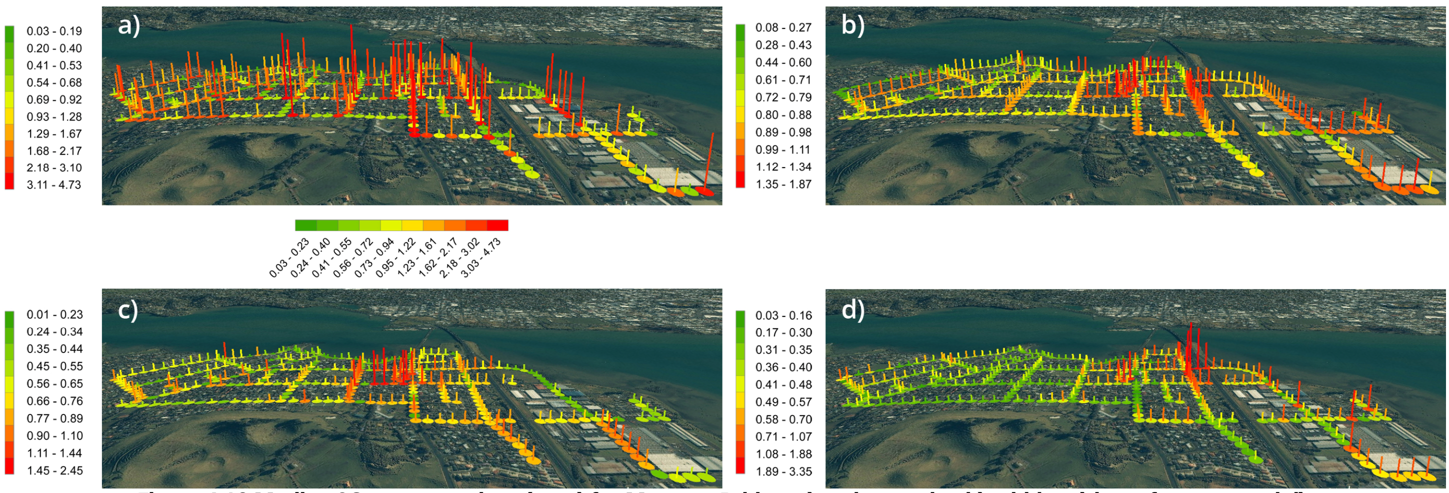

Figure 4.16 Median CO concentrations (ppm) for Mangere Bridge: a) early morning b) midday c) late afternoon and d) late evening

4.3.7 Study limitations

The primary concern of our study, especially in regard to our sampling regime and analysis, was the limited number of runs performed. Fortunately, Peters et al. (2013) performed an additional analysis on their UFP dataset which has very important implications for our study. They cumulatively added random runs together to determine at what point the median values would converge with the medians of the entire dataset. It was found that of the 24 runs in Antwerp, only seven were needed and of the 20 in Mol, only six were needed - 70% less than were completed. Hence a viable and valid study can be rendered from a very small dataset like ours, of only five runs for each of the four time periods. A total of 40 runs across two areas is considerably more than the majority of studies cited herein, which sampled for only 2 - 10 days. Our study also had the advantage of systematic sampling times and we believe it is the first to comprehensively sample a dense street network (every street) across a study area to achieve complete spatial saturation.

Another factor which may have influenced our results is the influence of differing wind directions, combined with the direction and speed of the mobile sampling platform, potentially altering the intake of air and concentration of pollutants. This inherent limitation is one that is difficult to correct for and is absent from the discussion in most of these types of studies. We attempted to maintain a consistent cycling speed of 15 km/hr and raised the possibility that slower cycling speeds may be ideal to help counter the impact of faster winds during the day.

4.4 Conclusions

Many studies have demonstrated the impact of heavily-trafficked freeways on roadside concentrations but less is known about the diurnal variation of that impact and the comparative importance of smaller arterial roads. Previous studies (Clements et al. 2009; Zhou & Levy 2007) have put the spatial extent of primary traffic pollutants at 300 metres downwind but others have shown it can be wider very late at night and during very early mornings (Hu et al. 2009). We were able to confirm this for Auckland, New Zealand, with UFP and CO concentrations extending out over twice that distance.

We have also been able to clearly illustrate the shifting spatial impact of the freeway (decreasing during the day) and the importance of arterial routes during the midday and afternoon periods. Presumably this is due to a combination of higher winds trapping plumes within street canyons and the direct emissions from queued stop-start traffic within the canyons themselves. In addition, we have identified some interesting characteristics of local air quality - the spatial homogeneity of PM_{10} and CO at night and morning.

Undoubtedly, datasets containing fine-scale temporal and spatial variation of air pollution levels near highways are highly useful for exposure assessment and this is being increasingly emphasised (Padró-Martínez et al. 2012). We have advanced the understandings of spatio-temporal variation across two very dense residential street networks bisected by major highways, achieving complete neighbourhood saturation. Further, we have presented a new method of illustrating this variation in a simple-to-understand fashion, suitable for lay-audiences. The distance to which the influence of heavily-trafficked roads extends into residential communities holds a high degree of importance in determining long-term health outcomes for local residents. We feel such studies provide a useful insight for residents who may be interested in planning their activities in the area, throughout the day. For people with serious pre-existing health conditions, this is quite valuable information.

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References

Adams, C, Riggs, P & Volckens, J 2009, 'Development of a method for personal, spatiotemporal exposure assessment', *Journal of environmental monitoring,* vol. 11, no. 7, pp. 1331-9.

Araujo, JA 2011, 'Are Ultrafine Particles a Risk Factor for Cardiovascular Diseases?', *Revista Española de Cardiología (English Version),* vol. 64, no. 8, pp. 642-5. 10.1016/j.rec.2011.05.006.

Ash, C 2008, *Spatial and temporal variations in ultrafine particulate matter and other air pollutants throughout the morning near a major highway*, M.S Thesis, Tufts University.

Baldauf, R, Thoma, E, Hays, M, Shores, R, Kinsey, J, Gullett, B, Kimbrough, S, Isakov, V, Long, T, Snow, R, Khlystov, A, Weinstein, J, Chen, FL, Seila, R, Olson, D, Gilmour, I, Cho, SH, Watkins, N, Rowley, P & Bang, J 2008, 'Traffic and meteorological impacts on near-road air quality: Summary of methods and trends from the Raleigh near-road study', *Journal of the Air and Waste Management Association,* vol. 58, no. 7, pp. 865-78.

Barros, N, Fontes, T, Silva, MP & Manso, MC 2013, 'How wide should be the adjacent area to an urban motorway to prevent potential health impacts from traffic emissions?', *Transportation Research Part A: Policy and Practice,* vol. 50, pp. 113-28.

Bassok, A, Hurvitz, PM, Bae, CHC & Larson, T 2010, 'Measuring neighbourhood air pollution: The case of Seattle's international district', *Journal of Environmental Planning and Management,* vol. 53, no. 1, pp. 23-39.

Berghmans, P, Bleux, N, Int Panis, L, Mishra, V, Torfs, R & Van Poppel, M 2009, 'Exposure assessment of a cyclist to PM10 and ultrafine particles', *Science of The Total Environment,* vol. 407, pp. 1286-98.

Boogaard, H, Montagne, DR, Brandenburg, AP, Meliefste, K & Hoek, G 2010, 'Comparison of short-term exposure to particle number, PM10 and soot concentrations on three (sub) urban locations', *Science of The Total Environment,* vol. 408, no. 20, pp. 4403-11.

Buonanno, G, Lall, AA & Stabile, L 2009, 'Temporal size distribution and concentration of particles near a major highway', *Atmospheric Environment,* vol. 43, no. 5, pp. 1100-5.

Buonocore, JJ, Lee, HJ & Levy, JI 2009, 'The influence of traffic on air quality in an urban neighborhood: a community-university partnership', *American Journal of Public Health,* vol. 99, no. 3, pp. S629-35.

Choi, W, Hu, S, He, M, Kozawa, K, Mara, S, Winer, AM & Paulson, SE 2013, 'Neighborhood-scale air quality impacts of emissions from motor vehicles and aircraft', *Atmospheric Environment,* vol. 80, pp. 310-21.

Chow, JC, Watson, JG, Edgerton, SA & Vega, E 2002, 'Chemical composition of PM2.5 and PM10 in Mexico City during winter 1997', *The Science of The Total Environment,* vol. 287, no. 3, pp. 177-201.

Clements, AL, Jia, Y, Denbleyker, A, McDonald-Buller, E, Fraser, MP, Allen, DT, Collins, DR, Michel, E, Pudota, J, Sullivan, D & Zhu, Y 2009, 'Air pollutant concentrations near three Texas roadways, part II: Chemical characterization and transformation of pollutants', *Atmospheric Environment,* vol. 43, no. 30, pp. 4523-34.

Evans, KA, Halterman, JS, Hopke, PK, Fagnano, M & Rich, DQ 2014, 'Increased ultrafine particles and carbon monoxide concentrations are associated with asthma exacerbation among urban children', *Environmental Research,* vol. 129, pp. 11-9.

Fuller, CH, Brugge, D, Williams, PL, Mittleman, MA, Durant, JL & Spengler, JD 2012, 'Estimation of ultrafine particle concentrations at near-highway residences using data from local and central monitors', *Atmospheric Environment,* vol. 57, pp. 257-65.

Gilbert, NL, Woodhouse, S, Stieb, DM & Brook, JR 2003, 'Ambient nitrogen dioxide and distance from a major highway', *Science of The Total Environment,* vol. 312, no. 1–3, pp. 43-6.

Gramotnev, G & Ristovski, Z 2004, 'Experimental investigation of ultra-fine particle size distribution near a busy road', *Atmospheric Environment,* vol. 38, no. 12, pp. 1767-76.

Hagler, GSW, Baldauf, RW, Thoma, ED, Long, TR, Snow, RF, Kinsey, JS, Oudejans, L & Gullett, BK 2009, 'Ultrafine particles near a major roadway in Raleigh, North Carolina: downwind attenuation and correlation with traffic-related pollutants', *Atmospheric Environment,* vol. 43, no. 6, pp. 1229-34.

Hagler, GSW, Thoma, ED & Baldauf, RW 2010, 'High-resolution mobile monitoring of carbon monoxide and ultrafine particle concentrations in a near-road environment', *Journal of the Air & Waste Management Association,* vol. 60, no. 3, pp. 328-36.

Hitchins, J, Morawska, L, Wolff, R & Gilbert, D 2000, 'Concentrations of submicrometre particles from vehicle emissions near a major road', *Atmospheric Environment,* vol. 34, no. 1, pp. 51-9.

Hu, S, Fruin, S, Kozawa, K, Mara, S, Paulson, SE & Winer, AM 2009, 'A wide area of air pollutant impact downwind of a freeway during pre-sunrise hours', *Atmospheric Environment,* vol. 43, no. 16, pp. 2541-9.

Hu, S, Paulson, SE, Fruin, S, Kozawa, K, Mara, S & Winer, AM 2012, 'Observation of elevated air pollutant concentrations in a residential neighborhood of Los Angeles California using a mobile platform', *Atmospheric Environment,* vol. 51, pp. 311-9.

Kaur, S, Clark, RDR, Walsh, PT, Arnold, SJ, Colvile, RN & Nieuwenhuijsen, M 2006, 'Exposure visualisation of ultrafine particle counts in a transport microenvironment', *Atmospheric Environment,* vol. 40, no. 2, pp. 386-98.

Kaur, S, Nieuwenhuijsen, MJ & Colvile, RN 2005, 'Pedestrian exposure to air pollution along a major road in Central London, UK', *Atmospheric Environment,* vol. 39, no. 38, pp. 7307-20.

Kimbrough, S, Baldauf, R, Hagler, GW, Shores, R, Mitchell, W, Whitaker, D, Croghan, C & Vallero, D 2013, 'Long-term continuous measurement of near-road air pollution in Las Vegas: seasonal variability in traffic emissions impact on local air quality', *Air Quality, Atmosphere & Health,* vol. 6, no. 1, pp. 295-305.

Kingham, S, Longley, I, Salmond, J, Pattinson, W & Shrestha, K 2013a, 'Variations in exposure to traffic pollution while travelling by different modes in a low density, less congested city', *Environmental Pollution,* vol. 181, pp. 211-8.

Kingham, S, Pattinson, W, Pearson, AL, Longley, ID, Campbell, M & Apparicio, P 2013b, 'The use of a land use regression model to predict NO2 air pollution in two small areas of Auckland ', *Air Quality & Climate Change,* vol. 47, no. 3, pp. 40-4.

Kittelson, DB, Watts, WF & Johnson, JP 2004, 'Nanoparticle emissions on Minnesota highways', *Atmospheric Environment,* vol. 38, no. 1 SU -, pp. 9-19.

Kozawa, KH, Fruin, SA & Winer, AM 2009, 'Near-road air pollution impacts of goods movement in communities adjacent to the Ports of Los Angeles and Long Beach', *Atmospheric Environment,* vol. 43, no. 18, pp. 2960-70.

Kozawa, KH, Winer, AM & Fruin, SA 2012, 'Ultrafine particle size distributions near freeways: Effects of differing wind directions on exposure', *Atmospheric Environment,* vol. 63, pp. 250-60.

Langrish, JP, Bosson, J, Unosson, J, Muala, A, Newby, DE, Mills, NL, Blomberg, A & Sandström, T 2012, 'Cardiovascular effects of particulate air pollution exposure: time course and underlying mechanisms', *Journal of Internal Medicine,* vol. 272, no. 3, pp. 224-39.

Levy, JI, Houseman, EA, Spengler, JD, Loh, P & Ryan, L 2001, 'Fine particulate matter and polycyclic aromatic hydrocarbon concentration patterns in Roxbury, Massachusetts: a community-based GIS analysis', *Environmental Health Perspectives,* vol. 109, no. 4, pp. 341-7.

Longley, ID, Kingham, S, Dirks, K, Somervell, E, Pattinson, W & Elangasinghe, MA 2013, *Research Report 516: Detailed observations and validated modelling of the impact of traffic on the air quality of roadside communities*, New Zealand Transport Agency, Wellington.

Padró-Martínez, LT, Patton, AP, Trull, JB, Zamore, W, Brugge, D & Durant, JL 2012, 'Mobile monitoring of particle number concentration and other traffic-related air pollutants in a near-highway neighborhood over the course of a year', *Atmospheric Environment,* vol. 61, pp. 253-64.

Pakbin, P, Hudda, N, Cheung, KL, Moore, KF & Sioutas, C 2010, 'Spatial and Temporal Variability of Coarse ($_{PM10-2.5}$) Particulate Matter Concentrations in the Los Angeles Area', *Aerosol Science and Technology,* vol. 44, no. 7, pp. 514-25.

Pattinson, W 2009, *Cyclist exposure to traffic pollution: microscale variance, the impact of route choice and comparisons to other modal choices in two New Zealand cities*, MSc Thesis, University of Canterbury

Pearson, JF, Bachireddy, C, Shyamprasad, S, Goldfine, AB & Brownstein, JS 2010, 'Association between fine particulate matter and diabetes prevalence in the U.S', *Diabetes Care,* vol. 33, no. 10, pp. 2196-201.

Peters, J, Theunis, J, Van Poppel, M & Berghmans, P 2013, 'Monitoring PM10 and Ultrafine Particles in Urban Environments Using Mobile Measurements', *Aerosol and Air Quality Research,* vol. 13, pp. 509-22.

Pirjola, L, Lähde, T, Niemi, JV, Kousa, A, Rönkkö, T, Karjalainen, P, Keskinen, J, Frey, A & Hillamo, R 2012, 'Spatial and temporal characterization of traffic emissions in urban microenvironments with a mobile laboratory', *Atmospheric Environment,* vol. 63, pp. 156-67.

Qadir, RM, Schnelle-Kreis, J, Abbaszade, G, Arteaga-Salas, JM, Diemer, J & Zimmermann, R 2014, 'Spatial and temporal variability of source contributions to ambient PM10 during winter in Augsburg, Germany using organic and inorganic tracers', *Chemosphere,* vol. 103, pp. 263-73.

Reponen, T, Grinshpun, SA, Trakumas, S, Martuzevicius, D, Wang, ZM, LeMasters, G, Lockey, JE & Biswas, P 2003, 'Concentration gradient patterns of aerosol particles near interstate highways in the Greater Cincinnati airshed', *Journal of Environmental Monitoring,* vol. 5, no. 4, pp. 557-62.

Rodes, CE & Holland, DM 1981, 'Variations of NO, NO2 and O3 concentrations downwind of a Los Angeles freeway', *Atmospheric Environment (1967),* vol. 15, no. 3, pp. 243-50.

Roorda-Knape, M, Janssen, N, de Hartog, J, van VLiet, P, Harssema, H & Brunekreef, B 1998, 'Air pollution from traffic in city districts near major motorways', *Atmospheric Environment,* vol. 32, no. 11, pp. 1921-30.

Rowangould, GM 2013, 'A census of the US near-roadway population: Public health and environmental justice considerations', *Transportation Research Part D: Transport and Environment,* vol. 25, pp. 59-67.

Weuve, J, Puett, RC, Schwartz, J, Yanosky, JD, Laden, F & Grodstein, F 2012, 'EXposure to particulate air pollution and cognitive decline in older women', *Archives of Internal Medicine,* vol. 172, no. 3, pp. 219-27.

Wilson, JG, Kingham, S & Sturman, AP 2006, 'Intraurban variations of PM10 air pollution in Christchurch, New Zealand: Implications for epidemiological studies', *Science of The Total Environment,* vol. 367, no. 2-3, pp. 559-72.

Zhang, KM, Wexler, AS, Zhu, YF, Hinds, WC & Sioutas, C 2004, 'Evolution of particle number distribution near roadways. Part II: the 'Road-to-Ambient' process', *Atmospheric Environment,* vol. 38, no. 38, pp. 6655-65.

Zhou, Y & Levy, JI 2007, 'Factors influencing the spatial extent of mobile source air pollution impacts: a meta-analysis', *BMC Public Health,* vol. 7, no. 89, pp. 1-11.

Zhu, Y, Hinds, WC, Kim, S & Sioutas, C 2002a, 'Concentration and size distribution of ultrafine particles near a major highway', *Journal of the Air and Waste Management Association,* vol. 52, no. 9, pp. 1032-42.

Zhu, Y, Kuhn, T, Mayo, P & Hinds, WC 2006, 'Comparison of daytime and nighttime concentration profiles and size distributions of ultrafine particles near a major highway', *Environ Sci Technol,* vol. 40, no. 8, pp. 2531-6.

Zhu, YF, Hinds, WC, Kim, S, Shen, S & Sioutas, C 2002b, 'Study of ultrafine particles near a major highway with heavy-duty diesel traffic', *Atmospheric Environment,* vol. 36, no. 27, pp. 4323-35.

Zwack, LM, Paciorek, CJ, Spengler, JD & Levy, JI 2011, 'Characterizing local traffic contributions to particulate air pollution in street canyons using mobile monitoring techniques', *Atmospheric Environment,* vol. 45, no. 15, pp. 2507-14.

5. Chapter Five: Personal exposure modelling to assess the importance of residential proximity to the highway

Pattinson, W, Langstaff, J, Longley, I & Kingham, S 2014, 'Using an ambient air pollution exposure model to explore the impact of local residents' proximity to a major highway', under review in *Air Quality, Atmosphere and Health*

Abstract

Pollutant exposure models are generally applied to large populations living across wide urban areas. Far fewer studies exist where exposure is modelled for specific individuals within a localised population. We used a customised version of the US-EPA's Air Pollution Exposure Model (APEX) to simulate exposure levels for 54 individual residents living within a small study area (1.5 km^2) bisected by a heavily-trafficked highway in South Auckland, New Zealand. The model produced daily exposure estimates of nitrogen oxides (NO_x), carbon monoxide (CO) and particulate matter (PM_{10}) for the month of July, 2010. Inputs included pollutant and meteorological data monitored at sites positioned both upwind and downwind of the highway, as well as city monitoring sites north of the study area to represent work destinations. A local resident survey provided time-activity diary input. The model was run once using the resident's home locations, and four times with the population artificially placed 50 and 150 m downwind, as well as 50 and 150 m upwind, relative to the highway. For NO_x and CO, the population was 32 - 37% more exposed when positioned 50 m downwind and 16 - 18% less exposed at the upwind side (p<.001), compared to their actual home locations. An additional 100 m separation downwind resulted in a 56 - 70% drop in total mean exposure (p<.001) and the difference in exposure levels for certain occupations varied by up to a factor of eight (p<.05). PM_{10} exposure was comparatively stable across the area. The effect of residential proximity and position, occupation, work location and commute distance were assessed using a Generalised Linear Model (GLM) followed by post hoc testing. This unique application of APEX shows good promise as a planning tool for assessing the potential benefits of a buffer zone between major roads and residential homes, for particular population groups.

Keywords: exposure model, near highway, traffic emissions, carbon monoxide, nitrogen oxides

5.1 Introduction

An individual's exposure to urban air pollutants is primarily dependent on the environments they spend their time in and the quality of the air in which these environments are positioned within. Hazardous microenvironments and 'hot spot' zones throughout cities cause exposure between individuals to fluctuate substantially, even if they happen to be neighbours or live within the same household. This poses an interesting challenge for exposure science and epidemiology. A single fixed site monitor is an insufficient indicator of exposure for individuals living throughout a wide urban area. Ideally, air pollutant measurements, location and activity data are recorded as the person moves through time and space. Collecting any one of these data is typically highly labour-intensive, which seriously restricts the size of the study population, as well as the duration of the study. To estimate exposure for larger populations, a number of models can be applied. Since the mid-1980s, numerous statistical, deterministic and stochastic models have been developed and some of the earlier models are still in use. Current preferred techniques include Land Use Regression (LUR) and hybrid models, which incorporate multiple modelling aspects from a wide range of inputs. However, a hybrid approach almost always relies on one or more datasets to be artificially generated, which increases uncertainty, e.g. emissions dispersion, concentration interpolation, land use activity, extrapolation of population inputs, etc. The most reliable studies go one step further by validating and/or 'training' (refining) the hybrid model with real-world time-activity and microenvironment exposure data (personal measurements). Not all achieve this depth of validation, with most comparing modelled exposure to ambient results, and some are published with no validation at all. The complexity of human activity patterns, coupled with the difficulty of accounting for indoor sources, makes it a particularly challenging aspect of air quality research. Although still well within its infancy, personal and population exposure modelling has gained considerable momentum with the advent of small handheld pollution monitors, GPS devices and smartphones, and the most recent studies reflect this progress.

A research team in Münster, Germany, achieved a good agreement between modelled and measured PM_{10} and $PM_{2.5}$ exposure for ten participants using a global positioning system (GPS), activity diaries and ambient data, despite excluding monitored indoor microenvironment concentrations (Gerharz et al. 2013). Rather, indoor air quality was estimated using a mass balance model and previously determined emissions factors added for particular activities such as smoking and cooking. In terms of validation, this has an advantage over the probabilistic approach of randomly assigning indoor emission factors to a location. For example, a study in Lieria, Portugal, was able to compare modelled $PM_{2.5}$ results with those from personal exposure studies in other European cities, but did not include an attempt to validate with personal monitoring data (Dias & Tchepel 2014). The validation of model output is desirable but not always required, depending on the objectives of the study.

One of the earliest and most widely cited exposure models was a deterministic model, which, based on stepwise regression applied to a limited number of microenvironments (four) and predictor variables, was able to explain 64% of variance in exposure to respirable particles (Spengler et al. 1985). More than one decade later, another landmark study, EXPOLIS (Air Pollution Exposure Distributions of Adult Urban Populations in Europe), - this time a probabilistic (stochastic)model - estimated exposure to a suite of eight air toxics, based on personal monitoring of over 400 participants in five European cities (Jantunen et al. 1998). Adaptations of EXPOLIS have been used in multiple subsequent works including EXPOLIS-Milan, in which simulated office worker exposure to CO was found to closely match that of measured concentrations (Bruinen de Bruin et al. 2004).

The United States Environmental Protection Agency (US-EPA) has released a range of probabilistic exposure models dating back to the early 1990s.Following amendments to the National Ambient Air Quality Standards (NAAQS) in 1990,the first was pNEM (probabilistic National Exposure Model) which has been widely applied in ozone (O_3) and carbon monoxide (CO) studies (see Law et al. 1997 for an example). Other EPA models include the Hazardous Air Pollution Exposure Model (HAPEM), the Stochastic Human Exposure and Dose Simulation for Particulate Matter (SHEDS-PM) and the Air Pollution Exposure Model (APEX). All are designed to run exposure and/or inhalation (dose) simulations for large populations (groups of individuals) as they move across space and time, throughout a variety of microenvironments. APEX was developed during the early 2000s as an improvement on previous EPA exposure models and continues to be updated today; the current public release being version 4.5 (EPA 2012 -b). It is consistently cited by the scientific literature as being one of the key human exposure models available(Fujita et al. 2014; Georgopoulos et al. 2009; Isaacs et al. 2008; Özkaynak et al. 2013; Özkaynak et al. 2008; Xue et al. 2010; Zou et al. 2009). Further, it is one of the only air quality models worldwide that can be downloaded online free of charge and it is supported by an extensive user's manual.

APEX was recently applied and evaluated in a large-scale, multi-model study for the whole of Atlanta GA, USA (Dionisio et al. 2013). Modelled daily exposures to NO_x and CO were found to be in good agreement (r>.82) with those from hybrid models tested in the study, demonstrating the viability of using APEX as a standalone option. Dionisio et al. (2013) go on to state that exposure models will likely hold an advantage in fine-scale spatiotemporal applications and note the possible suitability for epidemiological investigations. However, a subsequent health effects-exposure investigation (cardiorespiratory emergency visits) did not produce stronger estimates of effect than those from ambient monitoring data, with the exception of the association between NO_x/CO and asthma/wheeze (Sarnat et al. 2013). While the authors were hoping to identify stronger relationships for other health effects, they accepted that the exposure model comes with a number of possible uncertainties within time-activity data, roadway emission predictions and building infiltration factors. Despite this finding, it is clear that spatiotemporally resolved personal exposure data have a future role in this area and associations will likely improve with model refinements and increased activity diary accuracy.

In this study, we use an adapted version of APEX to simulate the exposure of 54 near-highway residents to traffic-generated (NO_x, CO) and background source (PM_{10}) pollutants. APEX is typically used in conjunction with CHAD (Consolidated Human Activities Database), where simulated profiles are randomly assigned a time-activity profile and location within the study radius, based on user-defined demographic information. We removed the stochastic element by attaching time-activity data - gathered via an extensive survey - to specific exposure profiles (individual adults) living at precise geographic co-ordinates situated within the study area. Unlike previous population exposure studies covering wide urban areas, we focus on individuals living within close proximity to one another across a community no larger than 1.5 km^2. The profiles are divided into eight different occupational groups based on the proportion of time spent in common microenvironments. We also use continuously monitored air quality data from Federal Equivalent Method (FEM) instrumentation at several sites across the study area, as opposed to concentrations approximated from emissions or air dispersion models. The question of proximity and position of the home location relative to the highway is explored within the context of time spent away from the home, i.e. different travel patterns, occupations and recreational activities are the main drivers of varying exposures. Furthermore, we shift the population around the study area for subsequent APEX model runs in order to quantify the impact of proximity of the home. Much of the near-highway literature concludes that concentrations of primary traffic emissions (NO_x, CO, ultrafine particles) are typically elevated by approximately 50% at the roadside compared to 100 - 150 m downwind (Karner et al. 2010; Pattinson et al. 2014; Patton et al. 2014). For long-term health reasons, some studies are now recommending a minimum separation of all residential buildings from highways, e.g. 100 m (Barros et al. 2013), but little is known about who would actually benefit most from a separation of such a distance.

Our aims are fourfold. Firstly, we aim to simulate and compare exposures for worker and non-worker profiles assigned to a range of occupations. Secondly, we explore the effect of placing the study population directly within the roadside corridor (highest exposure zone) compared to further back from the road. We refer to this as the effect of proximity and position, relative to the highway and the direction of local winds, respectively. Thirdly, we assess which occupational groups would obtain the least and most benefit (estimated reduction in exposure) if their home was to be shifted a minimum of 100 m in either direction, out of the highway corridor. Finally, we look at other factors such as the effect of commute distance and location of the workplace.

Our study is novel in that we take a population exposure model and apply it to a fine-scale study on the exposure impact of residential proximity to a major emissions source. In addition, we believe it is the first personal exposure modelling study conducted for New Zealand.

5.2 Methods

5.2.1 Study area and study population

This study was an additional investigation built on a long-term highway corridor monitoring campaign described in detail by Longley et al. (2013). The primary study area of Otahuhu, South Auckland, featured three air quality and meteorological monitoring stations at 5 m downwind, 134 m downwind and 212 m upwind of the highway (Figure 5.1). This is a typical near-highway monitoring configuration, with the three stations providing one immediate roadside site (5 m downwind), one downwind background site (within the potential spatial extent of highway emissions) and one upwind background site (likely outside the potential extent of highway emissions). Figure 5.2 shows the position of the primary study area within Auckland city as well as the location of other air monitoring sites and resident work locations used in the model.

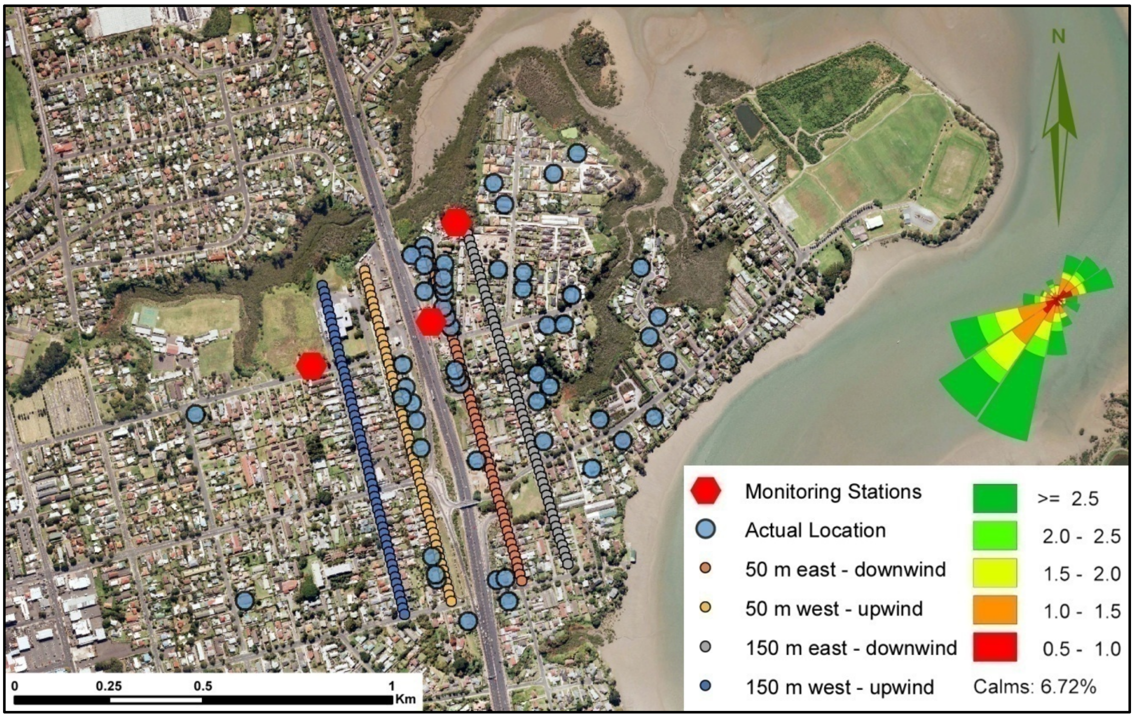

Figure 5.1 Study area showing wind direction and speed (m/s), location of monitoring stations, actual locations of study participants' homes and simulated participant home locations, relative to the highway. Note that actual resident locations are inexact to preserve anonymity (randomly shifted 1 - 2 properties either side of home address)

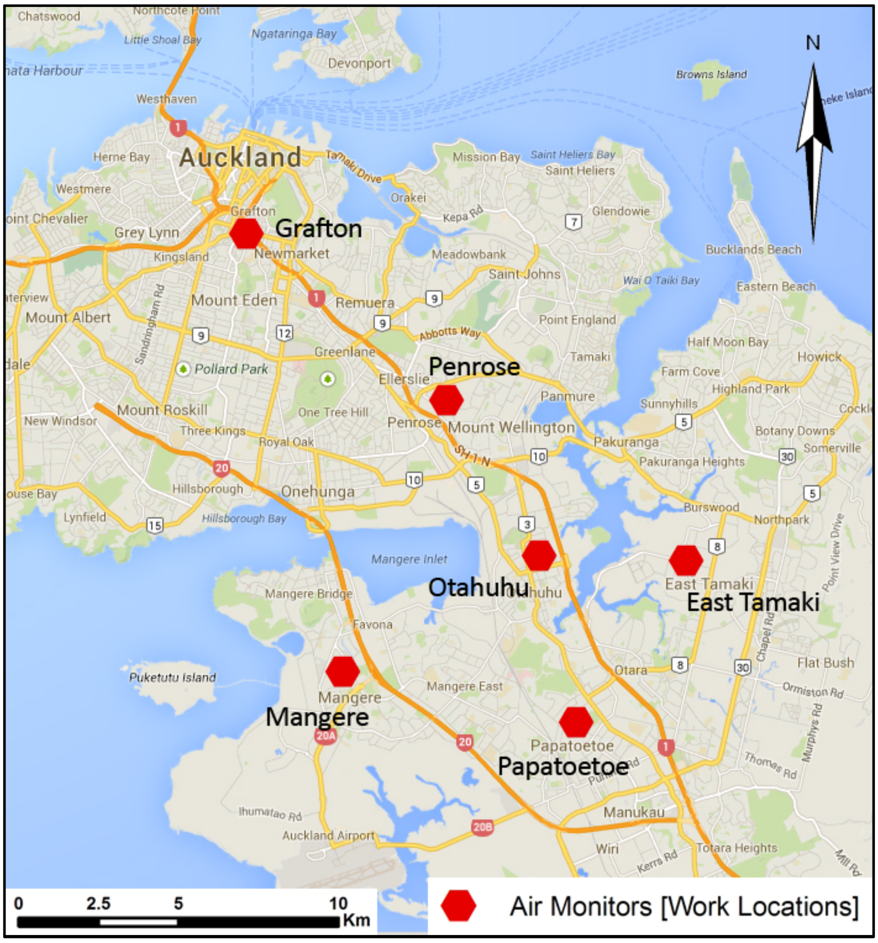

Figure 5.2 Map showing wider study area and positions of other monitoring stations. The primary study area of Otahuhu is near the centre of the map.

The study area is comprised of two census area units (CAUs) bisected by a six-lane highway. Otahuhu East (east of the highway in Figure 5.1) has a population of 2,088, a median age of 29.2 years and a median annual income of NZ$22,100 (Statistics New Zealand 2013a). Otahuhu North (west of the highway in Figure 5.1) has a population of 2,958, a similar median age of 29.6 years, and a lower median annual income of NZ$17,900 (Statistics New Zealand 2013b). The ethnicities are predominantly Pacific Island and Asian, with the combined population being 74% (East) and 84% (North). Otahuhu is one of the most economically deprived areas of Auckland, with approximately 50% of residents (15 years+) having an annual income of less than NZ$20,000, while the median for Auckland city as a whole is NZ$29,600. Although the climate is warm-temperate, the area is prone to cool winter temperatures (< 10°C) and high levels of humidity year-round can cause significant household mould issues. Mould, overcrowding and a lack of adequate heating are common challenges faced by South Auckland households (Bullen et al. 2008; Butler et al. 2003; Cheer et al. 2002). Health issues potentially arising from these living conditions, are further compounded by exposure to emissions and dust re-suspension from State Highway 1 - New Zealand's busiest freeway - with Annual Average Daily Traffic (AADT) in excess of 120,000 vehicles (NZTA 2013). Asthma, diabetes and heart disease are of primary concern, as these afflictions are over-represented by Māori and Pacific peoples (Cheer et al. 2002) and can be exacerbated by exposure to poor urban air (O'Neill et al. 2012).

5.2.2 Air quality and meteorological data

In order to capture the largest range of pollutant concentrations, which included particulate matter from wood smoke, air quality sampling took place during a mid-winter month; specifically, midnight 1st of July to midnight 31st of July, 2010.

Our campaign included the deployment of three stationary monitoring trailers within the primary study area (Figure 5.1). Each trailer was equipped with instrumentation to measure NO_x (chemiluminescence analyser; Model 200, Teledyne API), CO (gas filter correlation analyser; Model 300E, Teledyne API), PM_{10} (BAM; Model FH62C14, Thermo Scientific) and wind data (anemometer; Models A101M & W200, Vector Instruments) at a time resolution of 10 minute mean values. In order to include commuting in the exposure model, data from five additional air monitors (or work locations) were added. This gave a total of six work locations (including Otahuhu itself) represented by a local ambient air monitor, covering all participant commute-to-work destinations (Figure 5.2). Data for the two monitoring sites north of Otahuhu, Penrose and Grafton (Figure 5.2), were sourced from the Auckland Council which operates identical models of instrumentation (Auckland Council 2005). As the local council does not have other monitoring sites in the vicinity of South Auckland, the other three destinations of East Tamaki, Papatoetoe and Mangere used replicate data from the upwind background site shown in Figure 5.1. Note that all three sites are similarly positioned approximately 215 m upwind from a major road (Figure 5.2). Essentially we can either make the assumption that our upwind background site represents levels that would be found at a similar site within the neighbouring suburbs, or that the local worker does not leave their home suburb, i.e. all local workers who commute to a South Auckland destination are represented by a single air quality monitor for the wider area, while those who travel north are represented by air quality specific to that location. The important point is that the distance and duration of the daily commute is represented within the model. Due to traffic congestion and distance travelled, a worker commuting to Mangere will have a far higher commute period exposure than someone driving to a local destination within Otahuhu, while background ambient air quality is unlikely to be substantially dissimilar within the wider area.

The predominant wind direction for Auckland is southwest and to a lesser extent, northeast. Wind data for the entire study period is illustrated by the wind rose within Figure 5.1.

5.2.3 Survey methods

To gain a realistic understanding of how local residents actually spent their time, time-activity data were required for the model. Due to a lack of existing time-activity data for Auckland at the temporal resolution and level of detail required, we opted to conduct our own survey of local residents by means of door-to-door recruitment. Prior to conducting the surveys, the survey was reviewed and approved by the University of Canterbury Human Ethics Committee (HEC 2011/94). The aim was to recruit 25 participants from within the immediate roadside corridor (<150 m down/upwind) and 25 outside of the corridor, yet still within potential influence of the highway (>150 m and <500 m down/upwind). Some residents asked the interviewer to return at a different time. In keeping these appointments, the number of participants exceeded the target by four. Each participant was asked to provide a timeline of their movements for a typical week. Targeted door-to-door recruitment for the purposes of time-activity surveying has been used in previous exposure modelling research (Brugge et al. 2013; Kaufman et al. 2012). With the exception of short commutes or trips within the local area (15 minute trips), each activity lasted a minimum of 30 minutes. For most participants in full-time employment, their Monday to Friday schedule was generally identical, but punctuated by regular sports practice, club meetings, shopping and social outings on particular evenings. The majority of part-time workers and the unemployed or retired also had routine schedules that generally revolved around child care (school times) and/or regular recreational activities. Common weekend activities included attending church, visiting friends/family and local recreation such as sports and fishing. None of the participants routinely left the wider study area and we were not interested in factoring in atypical movements such as long-distance travel.

As this study only focuses on exposure and not inhaled dose, it was not necessary to gather sensitive demographic data such as age, height and weight. However, participants were asked to provide their work location, type of employment and type of work environment (building and ventilation type), as well as the approximate location (the suburb) of any regular activities outside of work. These data were used in combination with the time-activity diaries to assign the range of microenvironments and air monitoring locations that participants passed through over a typical week.

5.2.4 Exposure model input and configuration

APEX allows for a highly complex variety of model inputs which can be used to estimate exposure and dose for individuals living and working in all types of microenvironments. Outcomes are dependent on a wide range of environmental (ventilation systems, presence of gas utilities, air conditioning, vehicle speed, window use, etc.) and physiological parameters (age, gender, weight, height, etc.). We omitted much of this information and stripped APEX down to its base model design, which is the same as for many personal exposure models. The following equations and conceptual diagram are taken from the European EXPOLIS study (Jantunen et al. 1999), which describes the exact nature in which APEX has been adapted for our use:

$$E_{tot} = \sum_i f_i * C_i$$

where:

E_{tot} = total exposure, expressed as an average concentration for the exposure period
f_i = time fraction spent in the microenvironment
C_i = concentration in the microenvironment

Exposures for individual microenvironments are calculated as:

$$C_i = C_{out} * p_i + S_n$$

where:

C_i = concentration within the microenvironment
C_{out} = outdoor concentration at microenvironment location
p = pollutant penetration factor, often based on a measured Air Exchange Rate (AER)
S = attribution of sources in the indoor microenvironment

Figure 5.3 illustrates the functionality of a basic model setup, the only difference for our study being that APEX was run without the inclusion of pollutant concentrations originating from indoor sources, or S. As residents have control over sources originating from inside their homes but little to no influence on ambient air quality, including indoor sources was not an objective of this study.

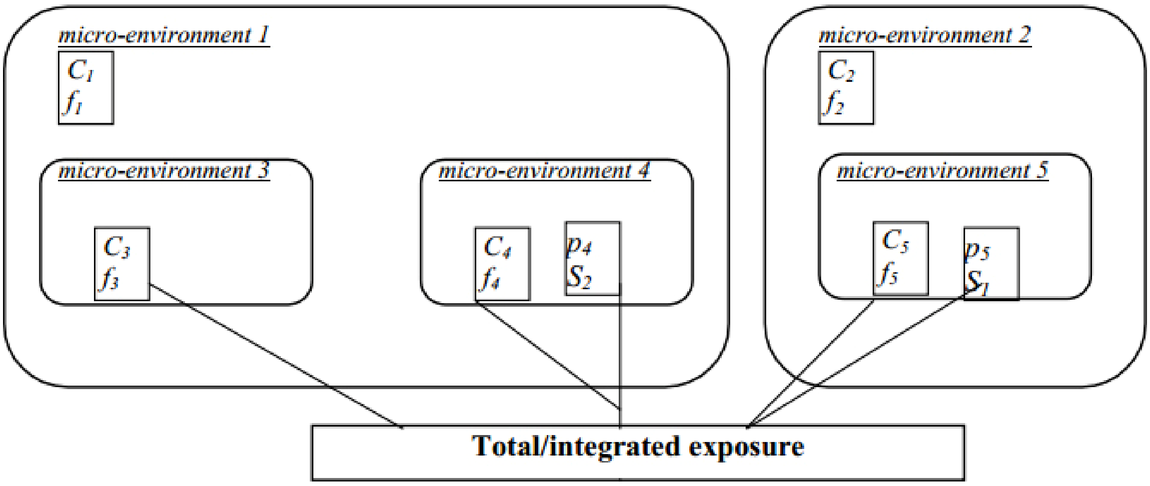

Figure 5.3 Conceptual framework of a basic personal exposure model (Jantunen et al. 1999)

In addition to our own local pollutant and meteorological data, we added Air Exchange Rates (AERs) measured inside a 1960s weatherboard home (windows and doors closed) situated next to the downwind background station (Figure 5.1). AERs were measured by continuously logging the decay of carbon dioxide (CO_2) concentrations (model GMP343, Vaisala) after releasing a set of 12 gram CO_2 cartridges. This technique has been developed and validated both in the lab and within field studies (You et al. 2012). The range of AERs (1.4 - 2.8 ac/hr) were then applied to all residential microenvironments within our study area. Although it would have been ideal to measure within both older and newer homes, the type of dwelling used is most representative of the housing stock within Otahuhu and throughout other low-income areas of South Auckland. AERs for larger building types, as well as penetration factors for vehicle types, were left to the default parameters based on data from US cities.

Table 5.1 provides an example of the detail of dairy input into APEX for a worker who wakes at 0530, spends 30 minutes getting ready and having breakfast and takes a 15-minute commute before commencing work at 0615. Each time a microenvironment changes, a different activity and location code apply. For 54 persons over 30 days, this required transforming written diary data into 11,322 lines of time-activity codes.

Table 5.1 Example of APEX time-activity input for an indoor labourer (descriptions in parentheses)

Dairy Day	Time	Duration	Activity	*(Activity)*	Location	*(Microenvironment)*
diaryP06_day3	0500	30	14500	*Sleep*	30125	*Bedroom - home residence*
diaryP06_day3	0530	30	14400	*Eat*	30121	*Kitchen - home residence*
diaryP06_day3	0600	15	17122	*Passive*	31110	*Car*
diaryP06_day3	0615	45	10000	*Work*	32200	*Industrial/factory/warehouse*
diaryP06_day3	0700	60	10000	*Work*	32200	*Industrial/factory/warehouse*

Although we had 10-minute pollutant data and APEX can perform simulations at this resolution (144 intervals per day), this level of detail was not required for estimating daily average and monthly mean exposure. All input and output was based on mean hourly data.

APEX is designed to run large simulations for thousands of profiles (individuals) across wide urban areas, randomly assigning profiles to home locations within the defined study zone. The profiles are formed from the EPA's Consolidated Human Activity Database (CHAD); a database detailing more than 30,000 time-activity days, which includes comprehensive demographic data. Modifying APEX to simulate exposure for specific individuals (to assign time-activity diaries to specific profiles) required a number of changes to the existing application. An updated version was developed to be used for this study; APEX 4.62. The most recent publicly available version is APEX 4.5, released in August 2012. For reference purposes, the latest available user's guide (EPA 2012 -a) and technical support document (EPA 2012 -b) should be used. EPA staff are continually updating APEX and encourage the submission of suggestions for improvement.

5.2.5 Analysis of model output

The resultant mean exposure value for each individual (30-day simulation) was pooled into one of eight occupational groupings, based on time spent in common microenvironments (Table 5.2). All occupational groupings are self-explanatory with the exception of the unemployed or retired group. These profiles were divided into two groups, one being active and the other inactive. An unemployed or retired participant who spent more than 70% of their awake hours inside their home (not going outside, or leaving the property), was defined as inactive. Additional analyses were performed by applying a Generalised Linear Model (GLM) to the groupings. The primary model tested proximity and position of home location, along with occupational group, as the main effects. Post hoc Bonferroni tests were used to assess significance between means for all possible pairings by occupation and position relative to the highway, i.e. pairs both within and between exposure groupings. A second GLM tested the effect of commute distance and work location on exposure. A single GLM could not be used alone due to a lack of variance across categorical variables, e.g. all unemployed/retired profiles have the same work location of 'Home'. For clarification, all variables used in the analyses are provided in Table 2. To check for any bias within the models, relationships between all variables were tested within a correlation matrix. All analyses were tested for significance at alpha level .05 but are reported as <.05, <.01 or <.001, as per the results. The analyses were run within a statistical software package (Statistica 10, StatSoft).

Table 5.2 Variables used for analyses and APEX microenvironments assigned to occupations

Variable	Variable Type	Units	Example Input
Main effects	**Independent**		
Proximity/Position	Categorical	Metres and position relative to wind direction	50Downwind, 150Downwind
Occupational Group	Categorical	Group names	Professional/Technical, Teacher/Student
Commute Distance	Continuous	Kilometres	Integer
Work Location	Categorical	Location names	Penrose, Grafton
Pollutants	**Dependent**		
NO_x	Continuous	µg/m^3	Integer
CO	Continuous	ppm	Integer
PM_{10}	Continuous	µg/m^3	Integer
Occupation	**Microenvironment**	**Method**	**Parameter Type**
Unemployed/Retired	Indoor-Residence	Mass Balance	Air Exchange Rate
Labourer - Outdoor	Outdoor-Residential	Factors	Proximity
Labourer - Indoor	Indoor-Industrial, factory, warehouse	Mass Balance	Air Exchange Rates
Prof./Tech. etc.	Indoor-Office building	Mass Balance	Air Exchange Rates
Security	Mixed Indoor-Industrial and Outdoor	Mixed	Air Exchange Rates and Proximity
Driver	Vehicle-Car or Bus	Factors	Penetration
Students/Teachers	Indoor-School	Mass Balance	Air Exchange Rate

5.3 Results

5.3.1 Fixed station measurements

Table 5.3 Fixed station mean results from hourly measurements for July 2010. Refer to Figure 5.1 for map of monitoring locations

Fixed station position and pollutant	Mean (30 days)	SD	Min Hourly	Max Hourly	Median	95% CI
NO_x (µg/m^3)						
5 m east of highway - downwind, Otahuhu	138.0	113.2	0.0	776.7	124.9	10.1
134 m east of highway - downwind, Otahuhu	68.2	73.6	0.0	562.7	42.6	5.0
212 m west of highway - upwind, Otahuhu	66.2	71.2	4.1	499.6	37.9	4.8
109 m east of highway - downwind, Penrose	80.2	61.6	0.2	381.2	71.9	5.9
2 m south of busy road in urban street canyon, 250 m east of highway, Grafton (CBD)	184.1	126.4	0.0	662.7	168.6	13.4
CO (ppm)						
5 m east of highway - downwind, Otahuhu	0.94	0.83	0.04	5.84	0.79	0.07
134 m east of highway - downwind, Otahuhu	0.53	0.49	0.08	2.36	0.33	0.05
212 m west of highway - upwind, Otahuhu	0.55	0.62	0.08	3.32	0.28	0.04
109 m east of highway - downwind, Penrose	0.40	0.40	0.01	2.64	0.30	0.03
2 m south of busy road in urban street canyon, 250 m east of highway, Grafton (CBD)	1.34	0.95	0.00	4.67	1.26	0.10
PM_{10} (µg/m^3)						
5 m east of highway - downwind, Otahuhu	19.2	13.2	0.1	76.1	16.7	1.4
134 m east of highway - downwind, Otahuhu	21.2	14.5	0.8	96.4	17.4	1.6
212 m west of highway - downwind, Otahuhu	16.5	11.7	1.2	70.3	13.4	1.2
109 m east of highway - downwind, Penrose	17.2	11.3	0.0	71.6	15.1	1.3
2 m south of busy road in urban street canyon, 250 m east of highway, Grafton (CBD)	20.6	12.6	0.7	84.3	18.5	1.5

Table 5.3 provides the summary statistics for all local and work destination monitoring sites for the duration of the modelling campaign (refer to Figure 5.2

for geographical locations). Within the local study area, the monitor 5 m downwind (representing the roadside corridor) recorded concentrations ~50% (NO_x) and ~43% (CO) greater than each of the sites further back from the road, which were almost equal. Despite having considerably less traffic capacity (four lanes instead of six), measurements at the street canyon site were 25% (NO_x) and 30% (CO) higher than at the highway roadside in Otahuhu. Figure 5.4 illustrates the strength of the street canyon effect, with the Grafton site showing a clear bi-modal peak representing the rush hour traffic flows. The late rush hour peak at the highway area is suppressed by strong afternoon winds. Although there is a significant emissions source at Otahuhu, it is heavily modulated by local meteorology. This is important in the context of utilising resident's time-activity-location dairies, because there are major diurnal fluctuations in the spatial extent of traffic markers (wider during mornings and evenings). For a full discussion on spatial extent, see Pattinson et al. (2014). Variation in PM_{10} between sites was minimal.

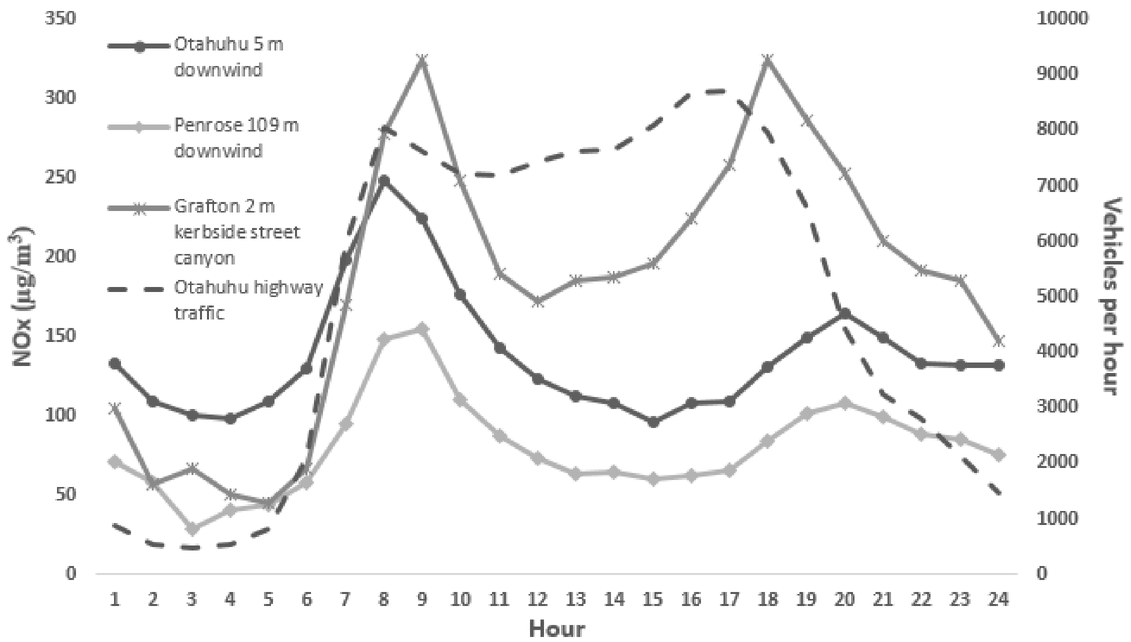

Figure 5.4 Diurnal NO_x concentrations closest to the roadway, July 2010

5.3.2 APEX model output

5.3.2.1 Proximity to highway

For resident proximity to highway (both sides of highway), there was an inverse relationship for NO_x (r=-.28) and CO (r =-.32), but no trend for PM_{10} (r=.00). When residents' actual home locations were shifted to the immediate roadside corridor at the downwind edge (50 m), exposure for the group increased by 32% for NO_x (F_{39}=10.3, p<.001) and 37% for CO (F_{39}=10.7, p<.001). However, when downwind separation was extended to 150 m, exposure decreased by 56% and 70% from the 50 m point, respectively (Table 5.4). Mean differences at the upwind side were only statistically significant at the 150 m mark. Exposure ranged from 33 - 48% less than 50 m within the downwind corridor, or from the residents' actual location (Table 5.4). Note that fourteen of the 54 simulated profiles actually reside within 50 m downwind of the highway (see Figure 5.1).

Table 5.4 Total group differences in ambient month-long exposure for July 2010 (1620 individual profile days simulated)
*Significant differences between groups are indicated in bold (*p*<.01, α=.05)

Proximity of home and pollutant	Mean (30 days)	SD	Min Daily	Max Daily	Median	95% CI	%Change in mean exposure from:		
NO_x (µg/m³)							Actual Location	50 m east - downwind	150 m east - downwind
Actual location	45.2	36.6	0.6	228.9	34.9	1.8			
50 m east - downwind	60	41.1	0.4	232.6	53.8	2	**32***		
50 m west - upwind	48.8	37.8	0.6	228.9	39.7	1.8	8	**-18***	
150 m east -downwind	26.3	21.9	0.5	124.1	20.6	1.1	**-42***	**-56***	
150 m west - upwind	25.2	20.7	1.8	158.3	18.7	1.0	**-44***	**-48***	-4
CO (ppm)							Actual Location	50 m east - downwind	150 m east - downwind
Actual location	0.27	0.22	0.00	1.32	0.22	0.01			
50 m east - downwind	0.37	0.25	0.00	1.35	0.34	0.01	**37***		
50 m west - upwind	0.31	0.23	0.01	1.32	0.26	0.01	15	**-16***	
150 m east - downwind	0.11	0.11	0.00	0.78	0.07	0.01	**-59***	**-70***	
150 m west - upwind	0.18	0.14	0.01	1.23	0.14	0.01	**-33***	**-42***	**64***
PM_{10} (µg/m³)							Actual Location	50 m east - downwind	150 m east - downwind
Actual location	7.0	3.9	0.4	27.1	6.3	0.2			
50 m east - downwind	7.0	4.0	0.3	27.1	6.2	0.2	0		
50 m west - upwind	6.7	3.8	0.3	27.1	6.0	0.2	-4	-4	
150 m east - downwind	7.6	4.1	0.3	27.1	6.9	0.2	9	9	
150 m west - upwind	5.8	3.3	0.4	26.8	5.3	0.2	-17	-13	**-24***

5.3.2.2 Proximity to highway and occupational group

The main effects on exposure were highly significant (p<.001) for all three pollutants (Table 5.5 & Table 5.6). Proximity and position were important, as was occupational group, irrespective of where participants lived. A basic sensitivity analysis, where the three groups of the smallest sample sizes were removed, showed that the main effects remained highly statistically significant at p<.001. In addition, there was no correlation between home position and occupational group (r=-0.06).

Table 5.5 GLM multivariate tests: Proximity to highway and occupational group

	Test	Value	F	Effect - df	Error - df	*p*
Intercept	Wilks	0.09	794	3	228	<.001
Proximity/Position	Wilks	0.27	32	12	604	<.001
Occupational Group	Wilks	0.32	15	21	655	<.001
Proximity/Position*Occupational Group	Wilks	0.70	1	84	683	.44

Table 5.6 Whole model R: Proximity to highway and occupational group

	Multiple - *R*	SS - Model	df - Model	MS - Model	SS - Residual	df - Residual	MS - Residual	F	*p*
NO_x	0.798	97514.4	39	2500.4	55705.9	229	242.2	10.3	<.001
CO	0.803	3.9	39	0.1	2.1	229	0.0	10.7	<.001
PM_{10}	0.690	1034.7	39	26.5	1136.9	229	4.9	5.4	<.001

Figure 5.5 - 5.7 illustrate the varying levels of exposure grouped by occupation and proximity/position relative to the highway. Outdoor labourers were the most exposed group and the unemployed or retired, inactive group, the least exposed. While variation within the results for $PM_{10}$was minimal, post hoc testing revealed multiple statistically significant differences within and between groups for NO_x and CO (Appendix 5.1 - 5.2). Those who spent more time doing outdoor activities at home, or more time within or near traffic at work faced increased exposure at the 50 m downwind position. NO_x exposure grew 47% (F_{229}=10.3, p=.005), 93% (F_{229}=10.3, p=.021) and 57% (F_{229}=10.3, p=.016) for the unemployed/retired - active, security guard and driver groups, respectively (Figure 5.4 and Appendix 5.1). For the same groups, CO exposure increased 53% (F_{229}=10.3, p<.001), 157% (F_{229}=10.3, p=.004) and 78% (F_{229}=10.3, p<.001). All occupations benefited from a further 100 m separation from the highway, with 53 - 75% reductions for both pollutants (p<.05). Again, the most substantial reductions were seen for the unemployed/retired - active, and the driver groups. Across all groups, the range between the least exposed (unemployed/retired - inactive) and most exposed group (outdoor labourer) varied by a factor of 6 and 8 (NO_x, CO) from 50 m downwind to 100 m downwind. This shows that persons living just

100 m from one another can potentially have an 8-fold variation in ambient exposure. Complete summary statistics for the occupational groups by proximity and position can be viewed in the appendix.

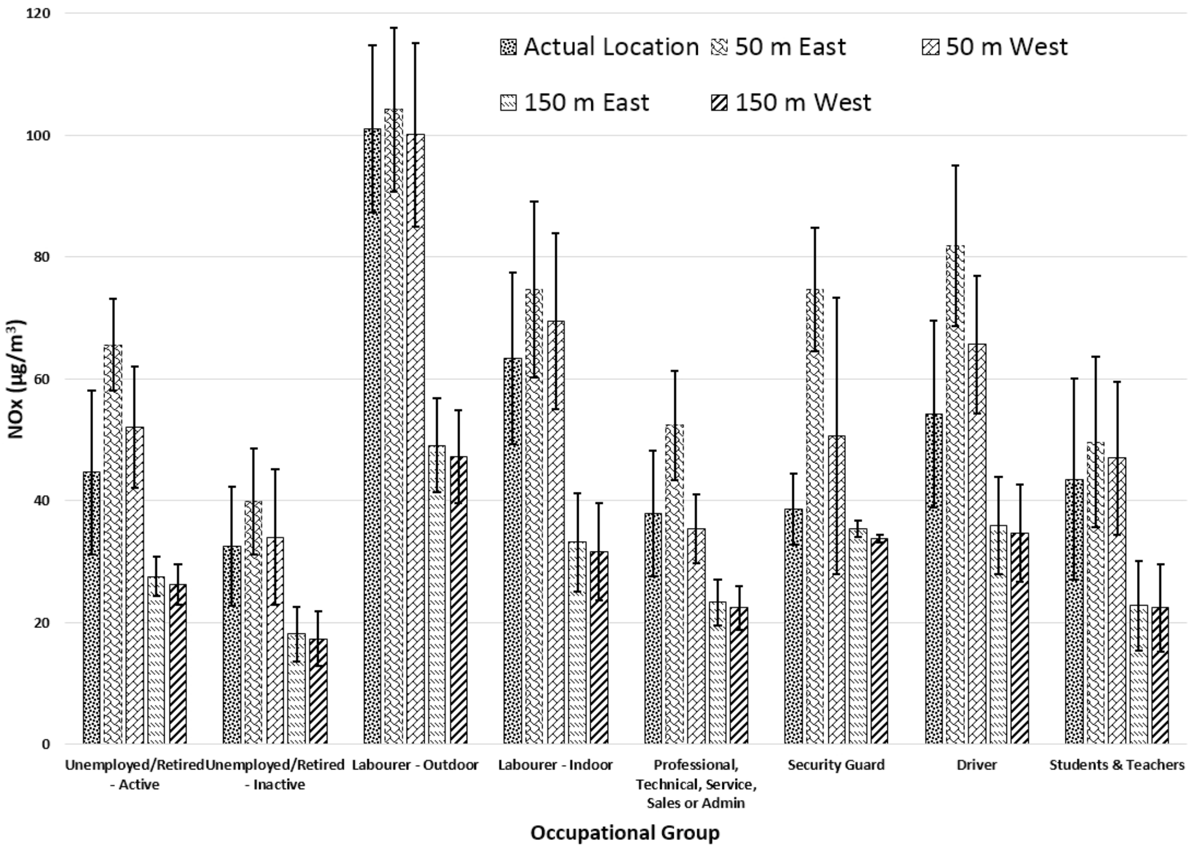

Figure 5.5 Simulated mean ambient NO_x exposure by occupational group for the month of July, 2010. Error bars denote 95% conf. limits

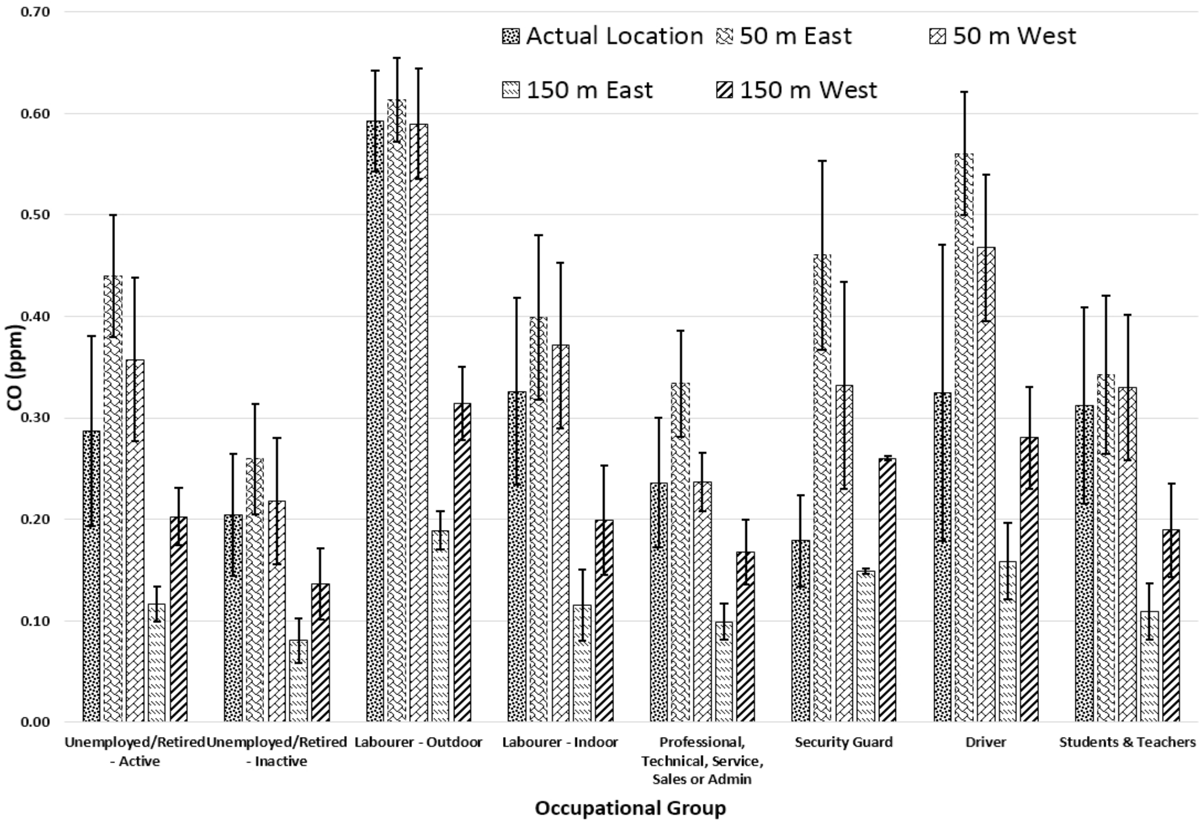

Figure 5.6 Simulated mean ambient CO exposure by occupational group for the month of July, 2010. Error bars denote 95% conf. limits

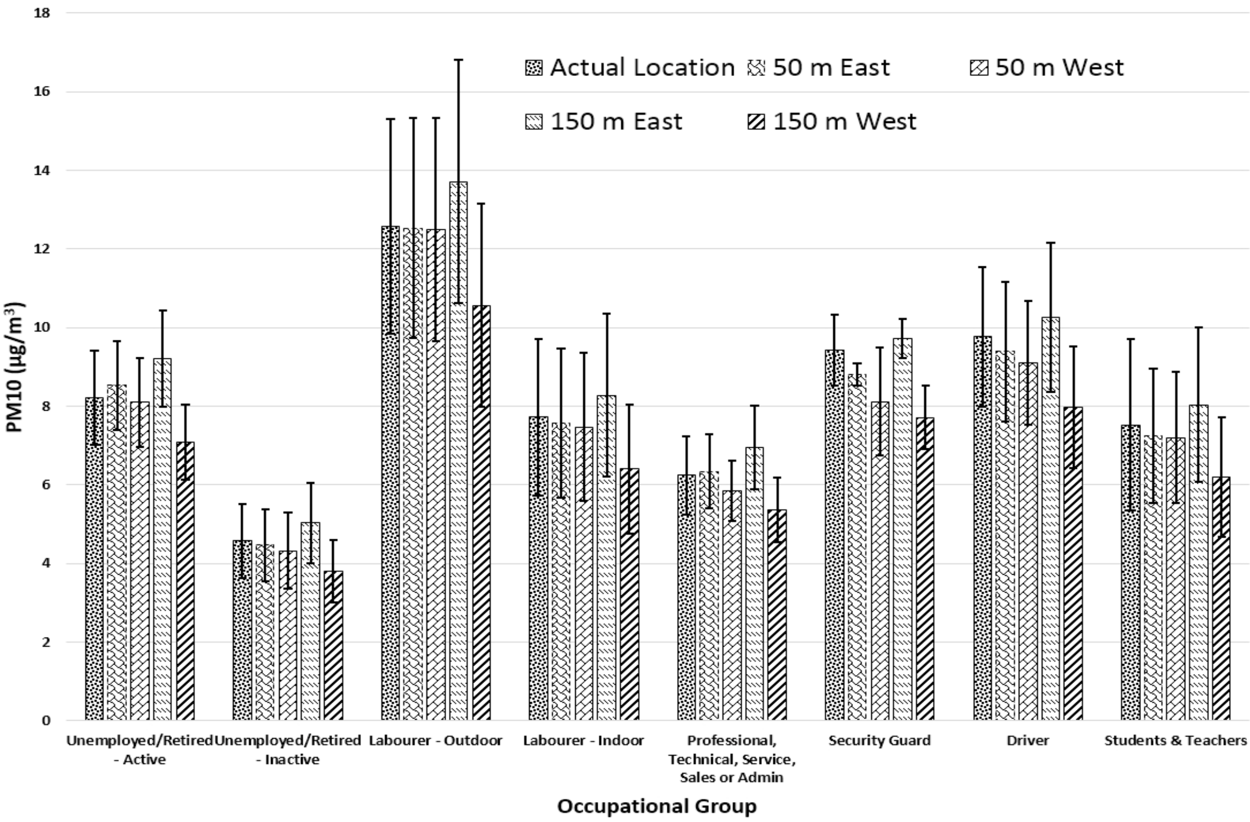

Figure 5.7 Simulated mean ambient PM_{10} exposure by occupational group for the month of July, 2010. Error bars denote 95% conf. limits

5.3.2.3 Proximity to highway, work location and commute distance

An additional GLM was run to test the effect of work location and commute distance (Table 5.7 - 5.8). For commute distance, there was a positive relationship for all three pollutants (NO_x, r=.18, CO, r=.20, and PM_{10}, r=.28). Both of these effects were highly significant at p<.001 (Table 5.7). Mean exposure values by work location and commute distance are illustrated in Figure 5.8. Although there was a moderate strength statistically significant correlation between work location and occupation (r=.41, p=0.03), this was only due to the unemployed/retired group all having the same work location of 'Home'. With this occupational group removed, the correlation ceased to exist (r=.006) yet the main effect of 'Work Location' remained significant at p<.001 within the GLM. Thus we can be confident that work location has a significant influence on the simulated profiles, independent of occupation.

Table 5.7 GLM multivariate tests: Proximity to highway, work location and commute distance

	Test	Value	F	Effect - df	Error - df	*p*
Intercept	Wilks	0.16	411	3	232	<.001
Commute Distance	Wilks	0.92	7	3	232	<.001
Proximity/Position	Wilks	0.29	30	12	614	<.001
Work Location	Wilks	0.53	9	18	657	<.001
Proximity/Position*Work Location	Wilks	0.79	1	72	694	.91

Table 5.8 Whole model R: Proximity to highway, work location and commute distance

	Multiple - *R*	SS - Model	df - Model	MS - Model	SS - Residual	df - Residual	MS - Residual	F	*p*
NO_x	0.766	89838	35	2566.8	63382.3	234	270.9	9.5	<.001
CO	0.776	3.6	35	0.1	2.4	234	0.0	10.1	<.001
PM_{10}	0.605	795.5	35	22.7	1376.1	234	5.9	3.9	<.001

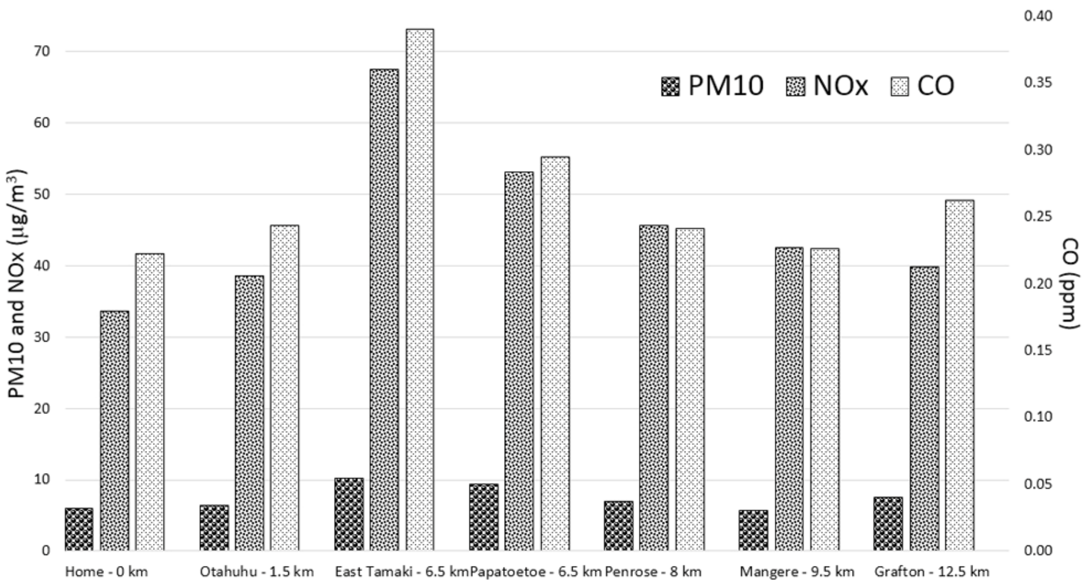

Figure 5.8 Simulated mean ambient pollutant exposure by work location and commute distance for the month of July, 2010

5.4 Discussion

5.4.1 Monitored ambient levels versus modelled exposure

The mean values recorded at the nearest associated monitoring station were a factor of 2.3 - 2.8 (NO_x, PM_{10}) times greater than the overall mean for the grouped (by proximity) exposure profiles. For CO, this divergence was even greater at 2.5 - 4.8 (Table 5.3 - 5.4). These basic results alone clearly highlight the protective effect of the residential building envelope, and the importance of time spent in other environments, away from home. Even with relatively high air exchange rates, naturally ventilated environments can help to downscale indoor levels to half those of outdoor, when no indoor emissions sources are present (Jones 2000; Ní Riain et al. 2003). Although indoor sources are important for personal exposure assessment, indoor residential sources of NO_x and CO are typically limited to unflued gas appliances, fireplaces and tobacco smoke. Conversely, ultrafine particles (UFPs) are emitted in very high numbers during numerous household activities, especially cooking (Buonanno et al. 2014). Wood burners, other indoor combustion activities and re-suspension from household movement can contribute to PM_{10} levels, but in this case, we are only interested in the impact of being in close proximity to a highway. The rationale for this is that the generation of indoor sources at home is something that can be controlled by individuals whereas outdoor air quality cannot. The pollutants chosen for our study are appropriately suited for representing fresh exhaust emissions (NO_x, CO), traffic-generated particulate, and the urban background plume (PM_{10}).

5.4.2 Overall effect of proximity

The overall effect of proximity to the highway on mean NO_x and CO exposure was substantial. If the study population were housed within 50 m downwind of the highway, exposure would be 32 - 37% greater than when dispersed throughout the community. If the separation was increased a further 100 m outside of the immediate downwind corridor, exposure would decrease 56 - 70% (Table 5.4). Exposure at the upwind side of the corridor was also considerably less (16 - 18%). The roadside to downwind background (134 m) decrease from the monitored data was lower at 51 and 44%, for NO_x and CO, respectively (Table 5.3). One factor explaining this difference may be time spent outside (by active individuals) elevating the roadside group mean, increasing the gap in simulated exposures.

The majority of roadside studies report an approximate 50% drop in NO_x and CO within 150 m, but no decay trend for PM_{10} (Karner et al. 2010). Our findings are in agreement and also show that when time-activity-location patterns are taken into account, ambient exposure reductions can potentially increase. This has important implications not only for planning and development, but also for social housing policy in regard to the placement of sensitive individuals and groups. The long-term impact of living within the highway corridor can be considerable for children, the elderly, and those suffering from significant illness and/or respiratory afflictions (Favarato et al. 2014; Perez et al. 2013). This is a concern within the local study context as its population suffers from disproportionately high rates of respiratory disease and diabetes (Cheer et al. 2002). Immediately south of Otahuhu, there is a primary school within 10 m of the highway which also features an early childhood centre on school grounds. For some residents living in South Auckland roadside communities, time spent away from the highway corridor could be quite limited.

5.4.3 Effect of occupation by proximity

To the best of our knowledge, no previous exposure modelling simulation has explored the influence of occupation, whereas personal monitoring by different occupations is more commonly investigated. Most of these tend to focus on high-exposure occupations such as those who work within heavily-trafficked zones (policemen, taxi drivers, toll gate employees) and potentially toxic workplace settings (commercial cleaning operations, beauty salons, auto body repair workshops) where volatile organic compound (VOC) vapours and aerosols can be present in high concentrations (Bello et al. 2009; Kisku et al. 2013; Tsigonia et al. 2010). Very few personal monitoring studies exist for NO_x and those for CO usually include significant indoor sources (di Marco et al. 2005; Raw et al. 2004). For better comparability, we refer to research utilising markers of fresh traffic emissions which do not have strong within-residence sources.

An occupational study of benzene (a highly carcinogenic VOC present in petrol fumes) exposure for fifty workers in Athens, Greece, found the strongest predictors were proximity of home location to heavy traffic, time spent outdoors and time spent in transportation (Chatzis et al. 2005). Time spent outdoors explained the link between occupation and high personal exposure levels. These findings are reflected by our results, with the outdoor labourers, security guards and drivers consistently the most exposed, while professionals, office workers, teachers and students were the least exposed (Figure 5.5 - 5.7). Similarly, exposure for those who spent more time outdoors at the home location (unemployed/retired, active) was 43 - 45% (NO_x, CO) and 46 - 50% (PM_{10}) greater than for those who spent most of their time indoors. For these groups, differences for NO_x and CO were only significant (p<0.05) within the roadside corridor (both sides) but shifting location did not render PM_{10} non-significant anywhere. Similar levels of significance, again for the roadside corridor only (NO_x, CO), were found for other paired groups such as outdoor labourer versus indoor labourer. Those working in large warehouses and factories were 28 - 37% (NO_x, CO) and 38 - 40% (PM_{10}) less exposed than carpenters working outside. Further back from the highway, the only occupations for which exposure was statistically significantly (p<0.05) higher for NO_x and CO was drivers and outdoor labourers; and only when compared to those who spent most of their time indoors at home (unemployed/retired -inactive). With the exception of PM_{10}, these findings show that when living outside of the highway corridor, the effect of occupation is non-significant for most but remains somewhat important for drivers and outdoor labourers, who spend more time in traffic or may be working outside near busy roads.

These results also show that proximity of residence has a far stronger influence on personal exposure to ambient pollutants than occupation. A VOC study of 100 residents in London, UK, found that 50 - 75% of variability within personal exposure for most compounds was explained by the home environment (Delgado-Saborit et al. 2011). Extensive source apportionment work in Helsinki, Finland, concluded that traffic emissions were second only to domestic cleaners, as the strongest origin of indoor VOC concentrations in non-smoking households (Edwards et al. 2001). Another urban exposure project in Camden, USA, found that ambient concentrations of polycyclic aromatic hydrocarbons (PAH), from traffic emissions and industrial combustion, explained 44 - 96% of variability in personal exposures (Zhu et al. 2011). We can therefore be fairly confident that, in the absence of significant indoor and/or occupational sources, ambient data can be used in personal exposure estimation to obtain meaningful results. Much of the remaining variability for these studies is generally explained by exposures while commuting, which is discussed in section 5.4.4.

A further outcome from our analysis is that we have gained an indication of how differing occupation profiles would potentially benefit from the >100 m roadway separation recommended by the literature (Barros et al. 2013; Hystad et al. 2013). Likely owing to the weaker presence of north east winds blowing toward the leeward side (27% of all observations), increasing the separation of the group from 50 - 100 m was only significant (p<.05) at the windward side (downwind for 58% of hourly observations, Figure 5.1). The mean decrease downwind was 56% (NO_x) and 70% (CO) for the group and some occupations benefited more than others, but not by a great margin (5 - 7%).

Perhaps a more important finding is that the unemployed/retired - active, security guard and driver groups, who spent a large proportion of time in traffic and outdoors, would face a substantially increased exposure burden if living within the downwind corridor than if living elsewhere. Those working in ventilated offices, who spend less time outdoors for work and/or recreation, are afforded better long-term protection from ambient air. This is demonstrated by the results for those commuting to the CBD area (Grafton), who spent eight hours of each weekday inside mechanically ventilated office buildings. Despite being in the most polluted area (inner-city street canyon), NO_x exposure was lower than for those who worked at four (out of six) alternative locations, in different environments (Figure 5.8). This finding is supported by previous microenvironmental comparisons for office workers in Los Angeles, USA (Fujita et al. 2014) and Hertfordshire, UK (Kornartit et al. 2010). Comparatively, those working near traffic or outside are faced with higher exposure both during the day and then again when at home, especially if active with gardening and recreation in the evenings and during weekends. Gardening or tinkering in the yard was a regular activity for two thirds of our unemployed/retired - active participants. For our security guards, one was a mobile patrol officer and the other was positioned outdoors near a busy road. All occupations which involved spending a lot of time outside, near traffic or commuting in traffic resulted in higher exposure profiles than the unemployed/retired - inactive group who spent most of their time indoors at home (Figure 5.8).

5.4.4 Effect of commuting to different work locations

Although there was a slight positive relationship for exposure and commute distance(r=.18 - r=.28), it would have been disproportionately influenced by the four drivers and one security guard, who had the maximum commute distance of 100 km (each way) entered within the APEX commute module. This was the only way to represent maximum exposure to traffic emissions for up to eight hours of driving. There is no trend when plotting exposure values by commute distance to work location (Figure 5.8). It is clear from this figure that the type of work environment type has the dominant influence, rather than commute distance. The highest exposures are for the outdoor labourers (East Tamaki), followed by indoor labourers working in large industrial buildings (Papatoetoe, Penrose, Mangere), office workers at Grafton, those who work locally at Otahuhu (school teachers, students) and lastly, those who rarely leave home (Figure 5.8). While there is a slight increase for those who commute > 1.5 km verus those who do not (may explain higher CO at Grafton), the effect is non-linear. This is probably because APEX cannot account for the geographic positions of roadways nor roadway emission source strength; it only tracks the individual's movements between areas represented by different monitoring stations. Without these elements, it is unlikely that the model can adequately estimate the true proportion of daily exposure received while commuting, which a previous New Zealand monitoring study put at 20% for UFPs and 15% for CO (Kingham et al. 2013). Nonetheless, our results show that commuting to any destination besides East Tamaki (outdoor workers), added an additional 14 - 57% (NO_x) and 10 - 33% (CO) to mean daily exposure (Figure 5.8). Monitoring the contribution of commuting towards daily NO_x exposure is difficult because the samplers used are generally passive samplers which cannot temporally resolve concentrations. UFPs act as an ideal substitute as they are strongly correlated with NO_x emissions (Longley et al. 2005). An international UFP study calculated the range for UFPs to be 10 - 50% (Zhu et al. 2008) and another for black carbon found the commute accounted for 30 - 55% of daily exposure (Fruin et al. 2004). Thus the portions of total daily exposure received from commuting are within reasonable agreement with the ranges estimated by other studies, even though ranges are expected to be highly variable due to differences in local topography, meteorology and traffic composition, as well as commute duration. The heightened commuter ambient exposures found within our results are likely explained by the more rapid infiltration and air exchange rates experienced while travelling in vehicles (depending on vent/air con settings) compared to in larger, static microenvironments, rather than as a direct result of being in traffic.

5.4.5 Recent exposure modelling studies

Personal exposure modelling has made significant advancements in the past couple of years, with the more up-to-date studies accounting for indoor exposures and commuting, plus personal sampling for model verification. Moving away from population-based, citywide (mesoscale) simulations which utilise generated emissions data and/or proxy variable inputs, is likely to substantially improve the accuracy of personal exposure estimates. These individual results can thereafter be collated to build results for a wider population, which can form a stronger basis for epidemiological studies. An excellent example is a study for Münster, Germany, where researchers kriged ambient and local particulate concentrations over a 250 m^2 citywide grid, included GPS time-activity data, indoor emissions sources and indoor/outdoor ratios for transport microenvironments, achieving strong correlations between modelled and measured exposures (Gerharz et al. 2013). Daily averages for PM_{10} ranged between 17 - 126 $\mu g/m^3$ and agreement was as high as r=.94 at a resolution of 1 hr and r=.84 at 5 min. The maximum exposures reported by this work were a factor of 4.2 higher than ours (Appendix 5.3), which are more in line with an older study using pNEM in London, with the majority of profiles being between 5 and 30

$\mu g/m^3$ (Zidek et al. 2005). This may be a reflection of a tendency for the more primitive models to underestimate true exposure.

Current alternatives to kriging (spatial interpolation) include GIS-based LUR (Dons et al. 2014a; Dons et al. 2014b; Hannam et al. 2013) and GPS-based time-activity approaches (Breen et al. 2014; Dias & Tchepel 2014). An LUR model for NO_2 in Antwerp, Belgium, resulted in mean exposure of 11 - 36 $\mu g/m^3$ (Dons et al. 2014b). Assuming a kerbside NO_2/NO_x ratio of 31% (Wang et al. 2011), the estimated NO_2 portion for our roadside corridor mean individual exposures would closely match this range at 9 - 31 $\mu g/m^3$ NO_2 or 29 - 104 $\mu g/m^3$ NO_x (Appendix 5.1). A mixed-method study trialling a range of kriging and regression modelling techniques in the UK, calculated population mean results of 54 - 70 $\mu g/m^3$ for Blackpool and Manchester, respectively (Hannam et al. 2013). The best of these performed fairly well against results from personal passive samplers (r=.60 - .62). Further research in Hillsborough County, FL, USA, utilising data generated by the CALPUFF dispersion model, eventuated in an urban residential group mean exposure of 22 $\mu g/m^3$ and individual exposures up to 43 $\mu g/m^3$ (Gurram et al. 2014). The collective results from these NO_x studies are reasonably comparable to our group means of 25 - 60 $\mu g/m^3$ (Table 5.4, Appendix 5.1).

To our knowledge, only one publication has specifically applied APEX to a study population; in Atlanta, GA, USA (Dionisio et al. 2013). Although individual profiles were simulated, only median results at the zip code level were provided. While not directly comparable, median NO_x concentrations were 0.05 ppm or ~94 $\mu g/m^3$ (based on the molecular weight of NO_2) and CO 0.80 ppm; considerably greater than our mean exposures, which is explained by higher ambient concentrations in Atlanta. The authors noted good agreement between median zip code APEX results and associated central site monitors even though there was substantial spread between the lower and upper 95th percentiles.

A major ongoing exploration into near-highway exposures and health effects is the Near-Road Exposures and Effects of Urban Air Pollutants Study (NEXUS), conducted in Detroit, MI, USA (Vette et al. 2013). The exposures of asthmatic children living within 150 m of busy roads (AADT > 90,000) with differing levels of heavy duty vehicles are modelled and assessed, along with associated health outcomes. The basic framework of the model design is very similar to APEX, but is better refined than for our application within South Auckland. Ambient concentration spatiotemporal resolution is vastly improved by extending fixed-site monitoring data with AERMOD and AERLINE dispersion model outputs, and house-specific infiltration factors are derived from indoor monitoring. GPS data is collected and time spent in different microenvironments, estimated. The overarching model is termed the Exposure Model for Individuals (EMI). As with many previous studies, the authors emphasised the difficulties in dealing with indoor emissions sources. Preliminary results indicate elevated BC and $PM_{2.5}$ concentrations at homes and schools close to high volume roads. This mirrors previous findings for the same pollutants, for children attending schools near highways across the Netherlands (Van Roosbroeck et al. 2007).

5.5 Study Limitations

The limitations within the current study are not dissimilar to those faced by previous work, with all presenting clear strengths and weaknesses. The main criticism of our work is that we could have used enhanced spatial concentration data (dispersion from fixed site levels) at a finer temporal resolution (APEX can handle input at 10-minute intervals), combined with a greater number of measured local infiltration factors for varying microenvironments. With these improvements, our application of this version of APEX would be on par with the EMI employed by Vette et al. (2013).

Further limitations, that very few studies adequately address, include the inability in accounting for indoor sources, the restrictions of the APEX commute module, and the lack of model validation.
The challenges associated with including indoor resident-specific sources are widely acknowledged and improvements are ongoing (Dias & Tchepel 2014; Vette et al. 2013). Accurately estimating exposures while commuting is also problematic and currently best handled by in-traffic exposure models (Dons et al. 2014a) or LUR models that include traffic volumes/road source intensity. Although our APEX application did not account for this, the additional exposures received by commuters compared to non-commuters were in general agreement with previous studies (Fruin et al. 2004; Zhu et al. 2008). The inclusion of indoor sources and commuting exposure continues to be completely omitted from some projects due to associated complexities (Dons et al. 2014b; Stroh et al. 2012).

The validation of our results would only have been possible if we had the ability to sample in microenvironments with no indoor sources. This is unrealistic in the context of personal sampling where dust re-suspension from human activity and emissions from cooking activity and home heating cannot be completely eliminated. Therefore, it is appropriate to omit validation in ambient modelling studies with an absence of controlled microenvironments as the results are useful in the epidemiological analysis of health effects where ambient sources are the primary interest (Dionisio et al. 2013).

Despite all of the limitations mentioned herein, our results do not deviate wildly from the ranges found in previous modelling studies (Gurram et al. 2014; Hannam et al. 2013; Zidek et al. 2005). Finally, a larger population sample would have likely strengthened statistical associations between occupational groups at the interaction effect level and improved estimates of potential exposure benefits when moving further away from the highway.

5.6 Conclusions

We have demonstrated that the impact of living within the immediate downwind corridor could increase population group exposure to NO_x and CO by more than one-third; an additional 40 - 155% increase in mean ambient exposure for individuals, depending on occupation. Our results also show that, with a separation of an additional 100 m downwind, these levels drop by 56% for NO_x and 70% for CO, and that the benefit for those in certain occupations is slightly increased above others (5 - 7%). Individuals who had the added burden of working within or near traffic, especially outdoors, and those who liked to spend a lot of time in their gardens benefited most from a further separation from the highway while those who spent most of their time indoors at home, received the least benefit. In fact, the difference between these groups varied by a factor of 6 and 8 (NO_x, CO) over this distance (100 m downwind); those working in certain occupations and also living within the immediate roadside corridor are likely to be substantially more exposed than particular occupations just 100 m away. Those who commuted to work received an additional 14 - 57% NO_x and 10 - 33% CO exposure above those who stayed at home which was in line with estimates from previous studies for markers of primary traffic emissions (Fruin et al. 2004; Zhu et al. 2008). We also found that our mean exposure estimates were comparable to those reported by the most recent NO_x/NO_2 personal exposure modelling studies (Dons et al. 2014b; Gurram et al. 2014).

This study has provided an interesting insight into the exposures of near-roadway residents in South Auckland and contains some meaningful results, regardless of its limitations. It is a good 'first look' at personal exposure simulations for a New Zealand city and provides the foundation for future local studies, which could be expanded to focus on particular population subsets. Additionally, this unique application of a personal exposure model may help inform other highway proximity population exposure assessments in the context of time-activity patterns altering exposure. Our findings are especially useful or groups and individuals with pre-existing health conditions and for those who work in occupations where exposure to traffic pollution is already high. Developing an understanding of who is affected most by near-highway living, may help steer local land use policy in a direction that aims to protect the most vulnerable citizens. Future analyses could include socio-demographics such as age and ethnicity, combined with health status data, i.e. susceptible individuals. Such an application has the potential to inform epidemiological studies, as demonstrated by previous work, e.g. Sarnat et al. (2013).

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References

Auckland Council 2005, *The ambient air quality monitoring network in the Auckland Region,* , Technical Publication No. 296, Auckland Regional Council, Auckland.

Barros, N, Fontes, T, Silva, MP & Manso, MC 2013, 'How wide should be the adjacent area to an urban motorway to prevent potential health impacts from traffic emissions?', *Transportation Research Part A: Policy and Practice,* vol. 50, pp. 113-28.

Bello, A, Quinn, M, Perry, M & Milton, D 2009, 'Characterization of occupational exposures to cleaning products used for common cleaning tasks-a pilot study of hospital cleaners', *Environmental Health,* vol. 8, no. 1, p. 11.

Breen, MS, Long, TC, Schultz, BD, Crooks, J, Breen, M, Langstaff, JE, Isaacs, KK, Tan, Y-M, Williams, RW, Cao, Y, Geller, AM, Devlin, RB, Batterman, SA & Buckley, TJ 2014, 'GPS-based microenvironment tracker (MicroTrac) model to estimate time-location of individuals for air pollution exposure assessments: Model evaluation in central North Carolina', *Journal of Exposure Science & Environmental Epidemiology*.

Brugge, D, Lane, K, Padro-Martinez, L, Stewart, A, Hoesterey, K, Weiss, D, Wang, D, Levy, J, Patton, A, Zamore, W & Mwamburi, M 2013, 'Highway proximity associated with cardiovascular disease risk: the influence of individual-level confounders and exposure misclassification', *Environmental Health,* vol. 12, no. 1, p. 84.

Bruinen de Bruin, Y, Hanninen, O, Carrer, P, Maroni, M, Kephalopoulos, S, Scotto di Marco, G & Jantunen, M 2004, 'Simulation of working population exposures to carbon monoxide using EXPOLIS-Milan microenvironment concentration and time-activity data', *Journal of Exposure Analysis and Environmental Epidemiology,* vol. 14, no. 2, pp. 154-63.

Bullen, C, Kearns, RA, Clinton, J, Laing, P, Mahoney, F & McDuff, I 2008, 'Bringing health home: Householder and provider perspectives on the healthy housing programme in Auckland, New Zealand', *Social Science & Medicine,* vol. 66, no. 5, pp. 1185-96.

Buonanno, G, Stabile, L & Morawska, L 2014, 'Personal exposure to ultrafine particles: The influence of time-activity patterns', *Science of The Total Environment,* vol. 468–469, pp. 903-7.

Butler, S, Williams, M, Tukuitonga, C & Paterson, J 2003, 'Problems with damp and cold housing among Pacific families in New Zealand', *New Zealand Medical Journal,* vol. 116, no. 1177, pp. 1 - 8.

Chatzis, C, Alexopoulos, EC & Linos, A 2005, 'Indoor and outdoor personal exposure to benzene in Athens, Greece', *Science of The Total Environment,* vol. 349, no. 1–3, pp. 72-80.

Cheer, T, Kearns, R & Murphy, L 2002, 'Housing policy, poverty, and culture: 'discounting' decisions among Pacific peoples in Auckland, New Zealand', *Environment and Planning C: Government and Policy,* vol. 20, no. 4, pp. 497-516.

Delgado-Saborit, JM, Aquilina, NJ, Meddings, C, Baker, S & Harrison, RM 2011, 'Relationship of personal exposure to volatile organic compounds to home, work and fixed site outdoor concentrations', *Science of The Total Environment,* vol. 409, no. 3, pp. 478-88.

di Marco, GS, Kephalopoulos, S, Ruuskanen, J & Jantunen, M 2005, 'Personal carbon monoxide exposure in Helsinki, Finland', *Atmospheric Environment,* vol. 39, no. 15, pp. 2697-707.

Dias, D & Tchepel, O 2014, 'Modelling of human exposure to air pollution in the urban environment: a GPS-based approach', *Environmental Science and Pollution Research,* vol. 21, no. 5, pp. 3558-71.

Dionisio, KL, Isakov, V, Baxter, LK, Sarnat, JA, Sarnat, SE, Burke, J, Rosenbaum, A, Graham, SE, Cook, R, Mulholland, J & Özkaynak, H 2013, 'Development and evaluation of alternative approaches for exposure assessment of multiple air pollutants in Atlanta, Georgia', *Journal of Exposure Science and Environmental Epidemiology,* vol. 23, no. 6, pp. 581-92.

Dons, E, Kochan, B, Bellemans, T, Wets, G & Panis, LI 2014a, 'Modeling Personal Exposure to Air Pollution with AB2C: Environmental Inequality', *Procedia Computer Science,* vol. 32, pp. 269-76.

Dons, E, Van Poppel, M, Int Panis, L, De Prins, S, Berghmans, P, Koppen, G & Matheeussen, C 2014b, 'Land use regression models as a tool for short, medium and long term exposure to traffic related air pollution', *Science of The Total Environment,* vol. 476–477, pp. 378-86.

Edwards, R, Jurvelin, J, Saarela, K & Jantuen, M 2001, 'VOC concentrations measured in personal samples and residential indoor, outdoor and workplace microenvironments in EXPOLIS-Helsinki, Finland', *Atmospheric Environment,* vol. 35, pp. 4531-43.

EPA 2012 -a, 'Total Risk Integrated Methodology (TRIM) Air Pollutants Exposure Model Documentation (TRIM.Expo / APEX, Version 4) Volume 1: User's Guide'. U.S. Environmental Protection Agency, Durham.

EPA 2012 -b, 'Total Risk Integrated Methodology (TRIM) Air Pollutants Exposure Model Documentation (TRIM.Expo / APEX, Version 4.5) Volume 2: Technical Support Document'. U.S. Environmental Protection Agency, Durham.

Favarato, G, Anderson, HR, Atkinson, R, Fuller, G, Mills, I & Walton, H 2014, 'Traffic-related pollution and asthma prevalence in children. Quantification of associations with nitrogen dioxide', *Air Quality, Atmosphere & Health*, pp. 1-8.

Fruin, SA, Winer, AM & Rodes, CE 2004, 'Black carbon concentrations in California vehicles and estimation of in-vehicle diesel exhaust particulate matter exposures', *Atmospheric Environment,* vol. 38, no. 25, pp. 4123-33.

Fujita, EM, Campbell, DE, Arnott, WP, Johnson, T & Ollison, W 2014, 'Concentrations of Mobile Source Air Pollutants in Urban Microenvironments', *Journal of the Air & Waste Management Association.*

Georgopoulos, P, Isukapalli, S, Burke, JM, Napelenok, S, Palma, T, Langstaff, J, Majeed, M, He, S, Byun, D, Cohen, M & Vautard, R 2009, 'Air Quality Modeling Needs for Exposure Assessment form the

Source-To-Outcome Perspective', *EM, A&WMA's Magazine for Environmental Managers,* vol. 10, pp. 26-34.

Gerharz, LE, Klemm, O, Broich, AV & Pebesma, E 2013, 'Spatio-temporal modelling of individual exposure to air pollution and its uncertainty', *Atmospheric Environment,* vol. 64, no. 0, pp. 56-65.

Gurram, S, Stuart, AL & Pinjari, AR 2014, 'Impacts of travel activity and urbanicity on exposures to ambient oxides of nitrogen and on exposure disparities', *Air Quality, Atmosphere & Health*, pp. 1-18.

Hannam, K, McNamee, R, De Vocht, F, Baker, P, Sibley, C & Agius, R 2013, 'A comparison of population air pollution exposure estimation techniques with personal exposure estimates in a pregnant cohort', *Environmental Science: Processes and Impacts,* vol. 15, no. 8, pp. 1562-72.

Hystad, P, Demers, PA, Johnson, KC, Carpiano, RM & Brauer, M 2013, 'Long-term Residential Exposure to Air Pollution and Lung Cancer Risk', *Epidemiology,* vol. 24, no. 5, pp. 762-72.

Isaacs, K, Glen, G, McCurdy, T & Smith, L 2008, 'Modeling energy expenditure and oxygen consumption in human exposure models: accounting for fatigue and EPOC', *Journal of Exposure Science and Environmental Epidemiology,* vol. 18, no. 3, pp. 289-98.

Jantunen, M, Katsouyanni, K, Knöppel, H, Künzli, N, Lebret, E, Maroni, M, Saarela, K, Srám, R & Zmirou, D 1999, *Final Report: Air Pollution Exposure in European Cities: the EXPOLIS Study*.

Jantunen, MJ, Hanninen, O, Katsouyanni, K, Knoppel, H, Kuenzli, N, Lebret, E, Maroni, M, Saarela, K, Sram, R & Zmirou, D 1998, 'Air pollution exposure in European cities: the "EXPOLIS" study', *Journal of Exposure Science and Environmental Epidemiology,* vol. 8, no. 4, pp. 495-518.

Jones, NT, CA; Mark, D; Harrison, RM 2000, 'Indoor/Outdoor relationships of particulate matter in domestic home with roadside, urban and rural locations', *Atmospheric Environment,* vol. 34, pp. 2603-12.

Karner, AA, Eisinger, DS & Niemeier, DA 2010, 'Near-roadway air quality: synthesizing the findings from real-world data', *Environmental Science & Technology,* vol. 44, no. 14, pp. 5334-44.

Kaufman, JD, Adar, SD, Allen, RW, Barr, RG, Budoff, MJ, Burke, GL, Casillas, AM, Cohen, MA, Curl, CL, Daviglus, ML, Diez Roux, AV, Jacobs, DR, Jr., Kronmal, RA, Larson, TV, Liu, SL, Lumley, T, Navas-Acien, A, O'Leary, DH, Rotter, JI, Sampson, PD, Sheppard, L, Siscovick, DS, Stein, JH, Szpiro, AA & Tracy, RP 2012, 'Prospective study of particulate air pollution exposures, subclinical atherosclerosis, and clinical cardiovascular disease: The Multi-Ethnic Study of Atherosclerosis and Air Pollution (MESA Air)', *American Journal of Epidemiology,* vol. 176, no. 9, pp. 825-37.

Kingham, S, Longley, I, Salmond, J, Pattinson, W & Shrestha, K 2013, 'Variations in exposure to traffic pollution while travelling by different modes in a low density, less congested city', *Environmental Pollution,* vol. 181, pp. 211-8.

Kisku, GC, Pradhan, S, Khan, AH & Bhargava, SK 2013, 'Pollution in Lucknow City and its health implication on exposed vendors, drivers and traffic policemen', *Air Quality, Atmosphere & Health,* vol. 6, no. 2, pp. 509-15.

Kornartit, C, Sokhi, RS, Burton, MA & Ravindra, K 2010, 'Activity pattern and personal exposure to nitrogen dioxide in indoor and outdoor microenvironments', *Environment International,* vol. 36, no. 1, pp. 36-45.

Law, PL, Lioy, PJ, Zelenka, MP, Huber, AH & McCurdy, TR 1997, 'Evaluation of a Probabilistic Exposure Model Applied to Carbon Monoxide (pNEM/CO) Using Denver Personal Exposure Monitoring Data', *Journal of the Air & Waste Management Association,* vol. 47, no. 4, pp. 491-500. Retrieved 2014/07/01, from

Longley, ID, Inglis, DWF, Gallagher, MW, Williams, PI, Allan, JD & Coe, H 2005, 'Using NOx and CO monitoring data to indicate fine aerosol number concentrations and emission factors in three UK conurbations', *Atmospheric Environment,* vol. 39, no. 28, pp. 5157-69.

Longley, ID, Kingham, S, Dirks, K, Somervell, E, Pattinson, W & Elangasinghe, MA 2013, *Research Report 516: Detailed observations and validated modelling of the impact of traffic on the air quality of roadside communities*, New Zealand Transport Agency, Wellington.

Ní Riain, CM, Mark, D, Davies, M, Harrison, RM & Byrne, MA 2003, 'Averaging periods for indoor–outdoor ratios of pollution in naturally ventilated non-domestic buildings near a busy road', *Atmospheric Environment,* vol. 37, no. 29, pp. 4121-32.

NZTA 2013, *State Highway Traffic Data*, New Zealand Transport Agency, Wellington.

O’Neill, M, Breton, C, Devlin, R & Utell, M 2012, 'Air pollution and health: emerging information on susceptible populations', *Air Quality, Atmosphere & Health,* vol. 5, no. 2, pp. 189-201.

Özkaynak, H, Baxter, LK, Dionisio, KL & Burke, J 2013, 'Air pollution exposure prediction approaches used in air pollution epidemiology studies', *Journal of Exposure Science and Environmental Epidemiology,* vol. 23, no. 6, pp. 566-72. Original Article.

Özkaynak, H, Palma, T, Touma, JS & Thurman, J 2008, 'Modeling population exposures to outdoor sources of hazardous air pollutants', *Journal of Exposure Science and Environmental Epidemiology,* vol. 18, no. 1, pp. 45-58.

Pattinson, W, Longley, I & Kingham, S 2014, 'Using mobile monitoring to visualise diurnal variation of traffic pollutants across two near-highway neighbourhoods', *Atmospheric Environment,* vol. 94, pp. 782-92.

Patton, AP, Collins, C, Naumova, EN, Zamore, W, Brugge, D & Durant, JL 2014, 'An Hourly Regression Model for Ultrafine Particles in a Near-Highway Urban Area', *Environmental Science & Technology,* vol. 48, no. 6, pp. 3272-80.

Perez, L, Declercq, C, Iñiguez, C, Aguilera, I, Badaloni, C, Ballester, F, Bouland, C, Chanel, O, Cirarda, F, Forastiere, F, Forsberg, B, Haluza, D, Hedlund, B, Cambra, K, Lacasaña, M, Moshammer, H, Otorepec, P, Rodríguez-Barranco, M, Medina, S & Künzli, N 2013, 'Chronic burden of near-roadway traffic pollution in 10 European cities (APHEKOM network)', *European Respiratory Journal,* vol. 42, no. 3, pp. 594 - 605.

Raw, GJ, Coward, SKD, Brown, VM & Crump, DR 2004, 'Exposure to air pollutants in English homes', *Journal of Exposure Analysis and Environmental Epidemiology,* vol. 14, pp. S85-S94.

Sarnat, SE, Sarnat, JA, Mulholland, J, Isakov, V, Özkaynak, H, Chang, HH, Klein, M & Tolbert, PE 2013, 'Application of alternative spatiotemporal metrics of ambient air pollution exposure in a time-series epidemiological study in Atlanta', *Journal of Exposure Science and Environmental Epidemiology,* vol. 23, no. 6, pp. 593-605.

Spengler, JD, Treitman, RD, Tosteson, TD, Mage, DT & Soczek, ML 1985, 'Personal exposure to respirable particulates and implications for air pollution epidemiology', *Environmental Science and Technology,* vol. 19, no. 8, pp. 700-7.

Statistics New Zealand 2013a, *QuickStats About Otahuhu East*, Statistics New Zealand, Wellington.

Statistics New Zealand 2013b, *QuickStats About Otahuhu North* Statistics New Zealand, Wellington.

Stroh, E, Rittner, R, Oudin, A, Ardo, J, Jakobsson, K, Bjork, J & Tinnerberg, H 2012, 'Measured and modeled personal and environmental NO2 exposure', *Population Health Metrics,* vol. 10, no. 1, p. 10.

Tsigonia, A, Lagoudi, A, Chandrinou, S, Linos, A, Evlogias, N & Alexopoulos, EC 2010, 'Indoor Air in Beauty Salons and Occupational Health Exposure of Cosmetologists to Chemical Substances', *International Journal of Environmental Research and Public Health,* vol. 7, no. 1, pp. 314-24.

Van Roosbroeck, S, Jacobs, J, Janssen, NAH, Oldenwening, M, Hoek, G & Brunekreef, B 2007, 'Long-term personal exposure to PM2.5, soot and NOx in children attending schools located near busy roads, a validation study', *Atmospheric Environment,* vol. 41, no. 16, pp. 3381-94.

Vette, A, Burke, J, Norris, G, Landis, M, Batterman, S, Breen, M, Isakov, V, Lewis, T, Gilmour, MI, Kamal, A, Hammond, D, Vedantham, R, Bereznicki, S, Tian, N & Croghan, C 2013, 'The Near-Road Exposures and Effects of Urban Air Pollutants Study (NEXUS): Study design and methods', *Science of The Total Environment,* vol. 448, pp. 38-47.

Wang, YJ, DenBleyker, A, McDonald-Buller, E, Allen, D & Zhang, KM 2011, 'Modeling the chemical evolution of nitrogen oxides near roadways', *Atmospheric Environment,* vol. 45, no. 1, pp. 43-52.

Xue, J, McCurdy, T, Burke, J, Bhaduri, B, Liu, C, Nutaro, J & Patterson, L 2010, 'Analyses of school commuting data for exposure modeling purposes', *Journal of Exposure Science and Environmental Epidemiology,* vol. 20, no. 1, pp. 69-78.

You, Y, Niu, C, Zhou, J, Liu, Y, Bai, Z, Zhang, J, He, F & Zhang, N 2012, 'Measurement of air exchange rates in different indoor environments using continuous CO2 sensors', *Journal of Environmental Sciences,* vol. 24, no. 4, pp. 657-64.

Zhu, X, Fan, ZT, Wu, X, Jung, KH, Ohman-Strickland, P, Bonanno, LJ & Lioy, PJ 2011, 'Ambient concentrations and personal exposure to polycyclic aromatic hydrocarbons (PAH) in an urban community with mixed sources of air pollution', *Journal of Exposure Science and Environmental Epidemiology,* vol. 21, no. 5, pp. 437-49.

Zhu, Y, Fung, DC, Kennedy, N, Hinds, WC & Eiguren-Fernandez, A 2008, 'Measurements of Ultrafine Particles and Other Vehicular Pollutants inside a Mobile Exposure System on Los Angeles Freeways', *Journal of the Air & Waste Management Association,* vol. 58, no. 3, pp. 424-34.

Zidek, JV, Shaddick, G, White, R, Meloche, J & Chatfield, C 2005, 'Using a probabilistic model (pCNEM) to estimate personal exposure to air pollution', *Environmetrics,* vol. 16, no. 5, pp. 481-93.

Zou, B, Wilson, J, Zhan, F & Zeng, Y 2009, 'Air pollution exposure assessment methods utilized in epidemiological studies', *Journal of environmental monitoring,* vol. 11, pp. 475-90.

Appendices

Appendix 5.1 Summary NO_x ($\mu g/m^3$) statistics from APEX output. Significant differences between groups (p<.05) are highlighted in red.

Actual Location	*N (persons)*	*N (days simulated)*	Mean	SD	Min	Max	Median	95% CI	% Change From		
Unemployed/Retired - Active	9	270	44.6	32.7	1.4	148.8	34.2	3.9	-		
Unemployed/Retired - Inactive	12	360	27.9	20.8	0.6	105.0	23.3	2.1	-		
Labourer - Outdoor	2	60	101.0	51.5	2.5	215.0	94.9	13.0	-		
Labourer - Indoor	10	300	63.3	44.6	1.2	228.9	60.5	5.1	-		
Professional, Technical, Service,	9	270	38.0	28.7	1.5	141.1	31.1	3.4	-		
Security Guard	2	60	38.6	24.2	3.2	99.4	32.3	6.1	-		
Driver	4	120	46.0	32.0	2.3	134.9	38.6	5.7	-		
Students & Teachers	6	180	44.2	31.6	1.2	148.1	40.1	4.6	-		
Group Total	**54**	**1620**	**45.2**	**36.6**	**0.6**	**228.9**	**34.9**	**1.8**			
50 m Downwind (east)	*N (persons)*	*N (days simulated)*	Mean	SD	Min	Max	Median	95% CI	Actual Loc		
Unemployed/Retired - Active	9	270	65.6	35.9	1.1	148.8	66.7	4.3	47		
Unemployed/Retired - Inactive	12	360	36.8	22.1	0.5	122.4	35.5	2.3	32		
Labourer - Outdoor	2	60	104.2	52.5	2.5	216.2	97.6	13.3	3		
Labourer - Indoor	10	300	74.6	49.6	1.2	232.6	72.0	5.6	18		
Professional, Technical, Service,	9	270	52.4	33.2	0.4	147.9	49.8	4.0	38		
Security Guard	2	60	74.7	39.9	2.2	162.2	71.2	10.1	93		
Driver	4	120	72.2	42.7	2.0	168.2	70.6	7.6	57		
Students & Teachers	6	180	53.1	37.9	0.6	178.3	47.1	5.6	20		
Group Total	**54**	**1620**	**60**	**41.1**	**0.4**	**232.6**	**53.8**	**2**	**32**		
50 m Upwind (west)	*N (persons)*	*N (days simulated)*	Mean	SD	Min	Max	Median	95% CI	Actual Loc	50 m East	
Unemployed/Retired - Active	9	270	52.1	32.6	2.7	134.5	51.2	3.9	17	-21	
Unemployed/Retired - Inactive	12	360	29.3	23.1	0.6	110.4	22.8	2.4	5	-21	
Labourer - Outdoor	2	60	100.1	51.2	3.6	215.0	94.9	13.0	-1	-4	
Labourer - Indoor	10	300	69.5	47.1	1.8	228.9	65.8	5.3	10	-7	
Professional, Technical, Service,	9	270	35.4	22.9	1.9	113.5	29.6	2.7	-7	-32	
Security Guard	2	60	50.7	33.6	7.3	155.0	42.4	8.5	31	-32	
Driver	4	120	56.0	38.0	3.6	165.9	45.4	6.8	22	-22	
Students & Teachers	6	180	45.9	28.6	1.2	138.3	42.0	4.2	4	-14	
Group Total	**54**	**1620**	**48.8**	**37.8**	**0.6**	**228.9**	**39.7**	**1.8**	**8**	**-18**	
150 m Downwind (east)	*N (persons)*	*N (days simulated)*	Mean	SD	Min	Max	Median	95% CI	Actual Loc	50 m East	
Unemployed/Retired - Active	9	270	27.6	18.6	1.1	87.6	23.7	2.2	-38	-58	
Unemployed/Retired - Inactive	12	360	16.5	12.5	0.6	66.2	12.4	1.3	-41	-55	
Labourer - Outdoor	2	60	49.1	31.3	3.4	111.9	36.9	7.9	-51	-53	
Labourer - Indoor	10	300	33.2	27.5	1.0	124.1	24.8	3.1	-48	-56	
Professional, Technical, Service,	9	270	23.3	17.6	0.5	87.7	18.5	2.1	-39	-55	
Security Guard	2	60	35.4	23.4	3.2	95.2	27.9	5.9	-8	-53	
Driver	4	120	30.6	22.3	2.3	93.6	24.3	4.0	-33	-58	
Students & Teachers	6	180	23.7	20.2	0.8	97.7	17.7	3.0	-46	-55	
Group Total	**54**	**1620**	**26.3**	**21.9**	**0.5**	**124.1**	**20.6**	**1.1**	**-42**	**-56**	
150 m Upwind (west)	*N (persons)*	*N (days simulated)*	Mean	SD	Min	Max	Median	95% CI	Actual Loc	50 m West	150 m East
Unemployed/Retired - Active	9	270	26.2	16.9	2.7	90.9	22.9	2.0	-41	-50	-5
Unemployed/Retired - Inactive	12	360	15.7	12.0	2.4	80.8	12.2	1.2	-44	-46	-5
Labourer - Outdoor	2	60	47.2	30.5	12.7	137.0	40.6	7.7	-53	-53	-4
Labourer - Indoor	10	300	31.6	26.1	2.7	158.3	23.8	3.0	-50	-54	-5
Professional, Technical, Service,	9	270	22.4	16.5	1.8	84.4	17.7	2.0	-41	-37	-4
Security Guard	2	60	33.8	21.4	9.4	102.0	28.9	5.4	-12	-33	-4
Driver	4	120	29.4	20.7	7.7	103.6	23.3	3.7	-36	-48	-4
Students & Teachers	6	180	23.3	19.6	2.4	112.4	16.8	2.9	-47	-49	-2
Group Total	**54**	**1620**	**25.2**	**20.7**	**1.8**	**158.3**	**18.7**	**1.0**	**-44**	**-48**	**-4**

Appendix 5.2 Summary CO (ppm) statistics from APEX output. Significant differences between groups (*p*<.05) are highlighted in red.

Actual Location	*N (persons)*	*N (days simulated)*	Mean	SD	Min	Max	Median	95% CI	% Change From		
Unemployed/Retired - Active	9	270	0.29	0.22	0.00	0.98	0.23	0.03	-		
Unemployed/Retired - Inactive	12	360	0.18	0.13	0.00	0.67	0.15	0.01	-		
Labourer - Outdoor	2	60	0.59	0.31	0.03	1.25	0.55	0.08	-		
Labourer - Indoor	10	300	0.33	0.25	0.01	1.32	0.31	0.03	-		
Professional, Technical, Service,	9	270	0.24	0.18	0.00	0.85	0.20	0.02	-		
Security Guard	2	60	0.18	0.13	0.00	0.47	0.17	0.03	-		
Driver	4	120	0.26	0.21	0.01	0.86	0.21	0.04	-		
Students & Teachers	6	180	0.31	0.22	0.00	0.91	0.29	0.03	-		
Group Total	**54**	**1620**	**0.27**	**0.22**	**0.00**	**1.32**	**0.22**	**0.01**			
50 m Downwind (east)	*N (persons)*	*N (days simulated)*	Mean	SD	Min	Max	Median	95% CI	Actual Loc		
Unemployed/Retired - Active	9	270	0.44	0.25	0.01	1.03	0.45	0.03	53		
Unemployed/Retired - Inactive	12	360	0.25	0.16	0.01	0.80	0.23	0.02	42		
Labourer - Outdoor	2	60	0.61	0.32	0.03	1.29	0.58	0.08	4		
Labourer - Indoor	10	300	0.40	0.27	0.01	1.35	0.38	0.03	22		
Professional, Technical, Service,	9	270	0.33	0.21	0.00	0.91	0.31	0.02	41		
Security Guard	2	60	0.46	0.25	0.02	1.11	0.45	0.06	157		
Driver	4	120	0.46	0.29	0.02	1.14	0.44	0.05	78		
Students & Teachers	6	180	0.38	0.25	0.01	1.17	0.34	0.04	23		
Group Total	**54**	**1620**	**0.37**	**0.25**	**0.00**	**1.35**	**0.34**	**0.01**	**37**		
50 m Upwind (west)	*N (persons)*	*N (days simulated)*	Mean	SD	Min	Max	Median	95% CI	Actual Loc	50 m East	
Unemployed/Retired - Active	9	270	0.36	0.24	0.02	1.03	0.32	0.03	25	-19	
Unemployed/Retired - Inactive	12	360	0.19	0.14	0.01	0.71	0.18	0.01	10	-22	
Labourer - Outdoor	2	60	0.59	0.31	0.03	1.25	0.55	0.08	0	-4	
Labourer - Indoor	10	300	0.37	0.25	0.02	1.32	0.34	0.03	14	-7	
Professional, Technical, Service,	9	270	0.24	0.15	0.01	0.82	0.21	0.02	0	-29	
Security Guard	2	60	0.33	0.20	0.05	0.90	0.30	0.05	85	-28	
Driver	4	120	0.37	0.24	0.03	1.08	0.34	0.04	41	-20	
Students & Teachers	6	180	0.34	0.20	0.02	0.91	0.32	0.03	11	-10	
Group Total	**54**	**1620**	**0.31**	**0.23**	**0.01**	**1.32**	**0.26**	**0.01**	**15**	**-16**	
150 m Downwind (east)	*N (persons)*	*N (days simulated)*	Mean	SD	Min	Max	Median	95% CI	Actual Loc	50 m East	
Unemployed/Retired - Active	9	270	0.12	0.11	0.0	0.44	0.08	0.01	-59	-74	
Unemployed/Retired - Inactive	12	360	0.08	0.08	0.0	0.42	0.06	0.01	-57	-69	
Labourer - Outdoor	2	60	0.19	0.16	0.0	0.54	0.15	0.04	-68	-69	
Labourer - Indoor	10	300	0.12	0.12	0.0	0.78	0.07	0.01	-65	-71	
Professional, Technical, Service,	9	270	0.10	0.09	0.0	0.41	0.07	0.01	-58	-70	
Security Guard	2	60	0.15	0.12	0.0	0.43	0.14	0.03	-17	-68	
Driver	4	120	0.11	0.11	0.0	0.44	0.09	0.02	-56	-75	
Students & Teachers	6	180	0.11	0.11	0.0	0.48	0.08	0.02	-63	-70	
Group Total	**54**	**1620**	**0.11**	**0.11**	**0.00**	**0.78**	**0.07**	**0.01**	**-59**	**-70**	
150 m Upwind (west)	*N (persons)*	*N (days simulated)*	Mean	SD	Min	Max	Median	95% CI	Actual Loc	50 m West	150 m East
Unemployed/Retired - Active	9	270	0.20	0.13	0.02	0.70	0.17	0.02	-29	-43	74
Unemployed/Retired - Inactive	12	360	0.13	0.10	0.01	0.61	0.10	0.01	-26	-33	70
Labourer - Outdoor	2	60	0.31	0.19	0.07	1.02	0.28	0.05	-47	-47	66
Labourer - Indoor	10	300	0.20	0.16	0.01	1.23	0.15	0.02	-39	-46	72
Professional, Technical, Service,	9	270	0.17	0.12	0.02	0.78	0.13	0.01	-29	-29	70
Security Guard	2	60	0.26	0.18	0.05	0.90	0.23	0.04	45	-22	75
Driver	4	120	0.21	0.14	0.04	0.77	0.17	0.03	-19	-43	85
Students & Teachers	6	180	0.20	0.14	0.02	0.82	0.16	0.02	-35	-41	78
Group Total	**54**	**1620**	**0.18**	**0.14**	**0.01**	**1.23**	**0.14**	**0.01**	**-33**	**-42**	**64**

Appendix 5.3 Summary PM_{10} ($\mu g/m^3$) statistics from APEX output. Significant differences between groups (p<.05) are highlighted in red.

Actual Location	*N* (persons)	*N* (days simulated)	Mean	SD	Min	Max	Median	95% CI	% Change From		
Unemployed/Retired - Active	9	270	8.2	3.6	1.0	20.6	7.7	0.4	-		
Unemployed/Retired - Inactive	12	360	4.4	2.3	0.4	15.2	4.0	0.2	-		
Labourer - Outdoor	2	60	12.6	5.2	2.1	25.2	12.3	1.3	-		
Labourer - Indoor	10	300	7.7	4.5	0.8	27.1	6.8	0.5	-		
Professional, Technical, Service,	9	270	6.2	2.9	0.8	15.5	6.1	0.3	-		
Security Guard	2	60	9.4	3.5	3.6	22.4	9.1	0.9	-		
Driver	4	120	8.1	3.2	1.5	16.6	8.1	0.6	-		
Students & Teachers	6	180	6.9	3.7	0.6	19.5	6.2	0.1	-		
Group Total	**54**	**1620**	**7.0**	**3.9**	**0.4**	**27.1**	**6.3**	**0.2**	-		
50 m Downwind (east)	*N* (persons)	*N* (days simulated)	Mean	SD	Min	Max	Median	95% CI	Actual Loc		
Unemployed/Retired - Active	9	270	8.5	3.8	1.0	20.6	8.3	0.5	4		
Unemployed/Retired - Inactive	12	360	4.2	2.2	0.3	14.9	4.0	0.2	-3		
Labourer - Outdoor	2	60	12.5	5.3	2.0	26.0	12.1	1.3	0		
Labourer - Indoor	10	300	7.6	4.5	0.8	27.1	6.6	0.5	-2		
Professional, Technical, Service,	9	270	6.3	3.1	0.5	15.7	6.1	0.4	2		
Security Guard	2	60	8.8	3.7	1.9	21.9	8.7	0.9	-7		
Driver	4	120	8.0	3.7	1.5	16.7	8.2	0.7	-1		
Students & Teachers	6	180	6.8	3.7	0.6	19.5	6.2	0.5	-2		
Group Total	**54**	**1620**	**7.0**	**4.0**	**0.3**	**27.1**	**6.2**	**0.2**	**0**		
50 m Upwind (west)	*N* (persons)	*N* (days simulated)	Mean	SD	Min	Max	Median	95% CI	Actual Loc	50 m East	
Unemployed/Retired - Active	9	270	8.1	3.5	1.0	20.6	7.8	0.4	-1	-5	
Unemployed/Retired - Inactive	12	360	4.0	2.1	0.3	15.4	3.8	0.2	-8	-5	
Labourer - Outdoor	2	60	12.5	5.2	2.1	25.2	12.2	1.3	-1	0	
Labourer - Indoor	10	300	7.5	4.3	0.8	27.1	6.5	0.5	-3	-1	
Professional, Technical, Service,	9	270	5.8	2.6	0.7	14.6	5.7	0.3	-6	-8	
Security Guard	2	60	8.1	3.4	2.0	21.6	7.8	0.9	-14	-8	
Driver	4	120	7.8	3.0	1.6	15.4	7.7	0.5	-4	-3	
Students & Teachers	6	180	6.7	3.4	0.6	19.5	6.2	0.5	-4	-1	
Group Total	**54**	**1620**	**6.7**	**3.8**	**0.3**	**27.1**	**6.0**	**0.2**	**-4**	**-4**	
150 m Downwind (east)	*N* (persons)	*N* (days simulated)	Mean	SD	Min	Max	Median	95% CI	Actual Loc	50 m East	
Unemployed/Retired - Active	9	270	9.2	3.7	1.8	22.8	9.1	0.4	12	8	
Unemployed/Retired - Inactive	12	360	4.8	2.4	0.6	16.4	4.4	0.3	9	13	
Labourer - Outdoor	2	60	13.7	5.1	4.0	28.6	13.2	1.3	9	9	
Labourer - Indoor	10	300	8.3	4.6	1.6	30.2	7.2	0.5	7	9	
Professional, Technical, Service,	9	270	6.9	3.1	1.1	17.4	6.7	0.4	11	9	
Security Guard	2	60	9.7	3.5	3.6	22.4	9.7	0.9	3	10	
Driver	4	120	8.7	3.3	3.1	17.6	8.6	0.6	7	8	
Students & Teachers	6	180	7.4	3.7	1.4	21.9	6.6	0.5	8	10	
Group Total	**54**	**1620**	**8.6**	**4.1**	**0.6**	**30.2**	**6.9**	**0.2**	**23**	**23**	
150 m Upwind (west)	*N* (persons)	*N* (days simulated)	Mean	SD	Min	Max	Median	95% CI	Actual Loc	50 m West	150 m East
Unemployed/Retired - Active	9	270	7.1	3.0	0.7	19.9	6.9	0.4	-14	-12	-23
Unemployed/Retired - Inactive	12	360	3.6	1.8	0.4	10.0	3.3	0.2	-18	-10	-25
Labourer - Outdoor	2	60	10.6	4.3	2.3	26.8	10.2	1.1	-16	-15	-23
Labourer - Indoor	10	300	6.4	3.8	0.7	25.3	5.5	0.4	-17	-14	-23
Professional, Technical, Service,	9	270	5.4	2.5	0.9	14.5	5.2	0.3	-14	-8	-23
Security Guard	2	60	7.7	3.5	1.3	20.6	7.4	0.9	-18	-5	-21
Driver	4	120	6.8	2.8	1.0	15.4	6.6	0.5	-16	-13	-22
Students & Teachers	6	180	5.8	3.1	0.8	16.9	5.3	0.5	-17	-14	-23
Group Total	**54**	**1620**	**5.8**	**3.3**	**0.4**	**26.8**	**5.3**	**0.2**	**-17**	**-13**	-33

6. Chapter Six: Proximity to busy highways and resident perceptions of air quality

Pattinson, W, Longley, I & Kingham, S 2014, 'Near-highway air quality at two socioeconomically disparate residential suburbs', under review in *Health & Place*

Abstract

This study investigated linear trends in perceptions of air quality relative to residential proximity to busy highways, across two suburbs of South Auckland, New Zealand. While plenty is known about the spatial gradients of highway emissions, very little is known about variation of lay understanding at the fine spatial scale and whether there are gradients in severity of concerns. One-hundred and four near-highway residents were door-knocked and agreed to participate in a semi-structured interview on their knowledge and attitudes towards highway traffic emissions. Proximity to the highway edge varied within 5 - 380 m downwind and 13 - 483 m upwind. Likert-type ordered response questions were analysed using multivariate regression. Inverse linear relationships were identified for distance from highway and measures of concern for health impacts, as well as for noise (p<.05). Positive linear relationships were identified for distance from highway and ratings of both outdoor and indoor air quality (p<.05). Measures of level of income had no conclusive statistically significant effect on perceptions. Additional discussion was made surrounding participant's open-ended responses within the context of limited international research. Findings indicate that there may be quantifiable psychological benefits of separating residents just a short distance (40 m+) from highways and that living within such close proximity can be detrimental to wellbeing by restricting outdoor activity. This work lends additional support to the existing highway emissions exposure knowledge which recommends a separation of 100 m in the interests of protecting human health.

Keywords: environmental justice, ultrafine particles, NO_x, carbon monoxide, highway, traffic emissions, exposure, dispersion models, GIS, particulate matter

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6.1 Introduction

The importance of proximity to busy roads is a widely investigated topic in urban environmental science research. The behaviour of fresh vehicle emissions (composition, chemical transformation and interaction with meteorology) is relatively well-understood and the understandings of the effects on human health are steadily progressing. Numerous case studies have investigated associations between residence near high-volume roads and human health impacts, including impacts amongst vulnerable groups, such as children attending schools and vulnerable persons in low-income communities (Carrier et al. 2014a,b; Kim et al. 2004; Meng et al. 2008; Molitor et al. 2011). For some large cities, communities with close residential proximity to major highways are among the poorest which has given rise to exposure inequity research, commonly known as Environmental Justice (EJ). This has motivated the need for better regulatory monitoring representation, improved understandings of air quality at the neighbourhood scale (spatial variation) and the implementation of possible mitigation strategies (Fuller et al. 2012; Houston et al. 2013; Lee et al. 2009; Marshall et al. 2014; Rowangould 2013).

Most near-highway studies conclude that the spatial extents of markers of fresh exhaust emissions typically decline to background levels somewhere between 100 - 300 m perpendicular to the highway, with the exception of early morning hours, when the extent can be much wider (Hu et al. 2009; Karner et al. 2010; Pattinson et al. 2014; Patton et al. 2014). The health implications of living within a plume of elevated traffic pollution may be far reaching and can begin before birth. Reported statistically significant associations include heightened risk of premature birth and development of autism (Volk et al. 2011; Wilhelm et al. 2012). The development and exacerbation of childhood asthma is highly correlated with highway proximity (Clark et al. 2010; Evans et al. 2014) and exposure continues to affect those with respiratory issues throughout adulthood (Riley et al. 2012). More serious long-term associations for adults include coronary heart disease and stroke (Gan et al. 2010; Wilker et al. 2013). Over a 5-year exposure period, Gan et al. (2010) found that individuals consistently living ≤ 150 m away from highways were at higher risk of death from coronary heart disease compared to those who only lived there for part of the study period. In addition to the baseline long-term exposure implications, poorer communities are often faced with the increased burden of susceptibility due to pre-existing health issues and sub-standard living conditions in the home. For example, the exacerbation of the effects of asthma has been shown to be twice as strong for those in poverty (Meng et al. 2008). Other issues related to living at a busy roadside include exposure to noise, odour from fumes and dust re-suspension; all of which can contribute to decreased quality of life. Recent research on the spatial extent of ultrafine particles found that downwind concentrations were correlated with recorded noise levels (Shu et al. 2014) and there is even some evidence that long-term exposure to traffic noise can contribute to myocardial infarction as a result of stress (Sørensen et al. 2012).

These impacts on communities have led to recommendations to shift residential housing at least 100 - 150 m away from the road (Barros et al. 2013). While much is known about the potential benefits to respiratory health of reduced emissions exposure, the possible improvements to mental wellbeing are less clear. Although there is some evidence to suggest people are unhappier living next to highways, many are highly satisfied with the accessibility offered by their home location (Brereton et al. 2008; Hamersma et al. 2014). Since most urban air perception research has focused on point source emissions from heavy industry, there is still a lot of work to be done in the traffic pollution realm and recent studies are very few in number. One clear research gap is whether perceived air quality (or dissatisfaction) follows the same spatial pattern as observable physico-chemical air quality. Psychological impacts may also be more important than certain physical health outcomes, especially near roads where National Environmental Standards (NES) are not breached. A possible implication is that mental health outcomes may be just as important as respiratory health outcomes, but the two may not necessarily have the same spatial patterns.

In this paper, we explore perceptions of local air quality among residents near major highways in two urban areas with limited industrial sources of pollution, relatively effective dispersion due to flat terrain, low-rise buildings and a low prevalence of calm wind conditions. We give special focus to the effect of proximity to the highway on the views of local individuals. To our knowledge, opinions gathered in highway pollution research have not previously been assessed by strength and direction of linear trends with distance from highway. The main objective is therefore to explore the hypothesis that adverse feelings regarding pollution and noise will be strongest at the highway edge and satisfaction with air quality will improve with increasing distance from the highway. Some studies have suggested those in poverty feel more negatively about local air than the more affluent (Bickerstaff & Walker 2001), and thus we also test the influence of socioeconomic status on perceptions. We investigate this using both quantitative and qualitative methods, for two near-highway suburbs of South Auckland, New Zealand. Compared to larger international cities, urban air pollution receives limited public attention in Auckland, urban background concentrations are low and public awareness campaigns are uncommon. This study aims to obtain a snapshot of local perceptions and understandings of urban highway traffic pollution for a city where no comparable research exists. The goal is to gather an indicative picture by identifying themes in the narratives and linking these back to any quantitative outcomes, and not to fully explain the reasoning behind them.

6.2 Methods

6.2.1 Study areas

This research took place within two near-highway suburbs of South Auckland. Auckland is New Zealand's largest city, with a population of 1.4 million (Statistics New Zealand 2013a). Otahuhu East (Study Area 1, Figure 6.1) formed the initial study area and Mangere Bridge (Study Area 2, Figure 6.1), the second zone. Both study areas straddle separate but parallel major highways. The work presented here is an extension of a long-term measurement project designed to assess highway corridor air quality and the physical processes behind it (Longley et al. 2013; Pattinson et al. 2014). Otahuhu East is one of the most socioeconomically deprived areas of Auckland city and also one of the most ethnically diverse. It scores around 48% on the Ethnic Diversity Index which reaches a maximum of 70% throughout Auckland (Statistics New Zealand 2009). The broad ethnic categories of Pacific peoples (53.3%) and Asian (15.9%) encompass numerous groups, with some likely to identify with multiple ethnic origins, e.g. Fijian-Indian. The remainder is made of up of indigenous Māori (14.5%). Annual median income for Otahuhu is NZ$21,300 and all census meshblocks within the area are classified as the most socioeconomically disadvantaged, or 7 - 10 on the New Zealand Index of Deprivation or NZDep (Salmond et al. 2007). Mangere Bridge is equally diverse (49%) but is much less deprived, with median income (NZ$28,400) almost on par with the rest of Auckland as a whole (NZ$29,600). The largest ethnic group is European (51%), followed by Pacific peoples (35%), Māori (20%) and Asian (13%) (Statistics New Zealand 2013b). Although the census meshblocks next to the highway at Mangere Bridge are also 7 - 10 on the NZDep scale, they drop to 5 approximately 600 m west of the highway and right down to level 1 (least deprived) further west. While this social gradient exists west of the Mangere Bridge highway, it is important to point out that, for median personal income, a similar gradient seems apparent east of the Otahuhu highway (Figure 6.2).

In addition to the socioeconomic and ethnic diversity offered by the area, its residential buildings are in extreme proximity to the roadway edge (as close as 5 m) compared to previous studies assessing residential exposures (Fuller et al. 2013). Further, these two highways are home to some of the busiest daily traffic flows in the country - 122,000 vehicles per day at Otahuhu (State Highway 1) and 80,000 at Mangere Bridge (State Highway 20). Analysis of the physical air quality measurements found that long-term ambient levels of primary traffic emissions (NO_x, CO, UFPs) were at least 50% higher for residents living within the first 150 metres and that a clear spatial gradient could be observed up to 650 m downwind under cool, low wind speed conditions (Longley et al. 2013; Pattinson et al. 2014). Both areas are under the common influence of predominant south-westerly winds which typically provide substantial dispersion from mid-morning to late afternoon. North-easterly winds generally make up the remainder, with periods of winds parallel to the highways uncommon, meaning residents are consistently either upwind or downwind of the highway emissions source. No noise barriers exist along these specific sections of the highways and most homes are older (50+ years), single-storey detached dwellings. The wealth of existing air quality data collected for these areas during 2010 and 2011, combined with the diverging cultural backgrounds, provided an excellent opportunity to gain an insight into local resident's perceptions and feelings about living there.

Figure 6.1 Location of study areas within Auckland

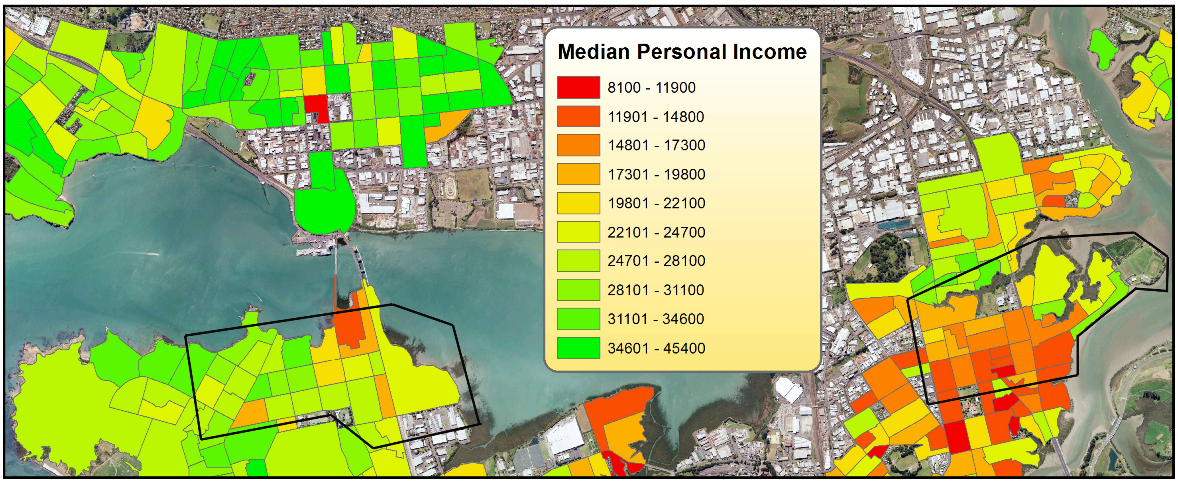

Figure 6.2 Median personal income by census meshblock. Based on 2013 Census data (Statistics New Zealand 2013a)

6.2.2 Survey methods

A semi-structured interview was designed with the goal of collecting data ranging from basic demographic information and simple response scale questions through to relatively detailed time-activity dairies and open-ended questions. Personal questions were limited to: number of adults in the home, number of children in the home, current occupation, personal income, household income, and whether or not the participant smoked cigarettes. A number of details about potential encounters with air pollutant sources were collected (indoor sources at the home, means of commuting, work environment, workplace suburb) and used in combination with the time-activity diaries to simulate resident's exposure using a personal exposure model (a separate study). Several of these early survey questions were relevant in leading into questions required for the current study e.g. workplace environment.

The last section of the semi-structured survey pertained to the focus of this paper. It consisted of 23 questions, of which 15 were Likert-type ordered response scale questions and 5 were open-ended questions, prompting the participant to elaborate on the reasoning behind their previous response scale answer. Participants were also free to comment or expand on any of their answers throughout the interview process, and many did so. The response scales were designed to be linearly continuous (from worst to best, or best to worst), rather than hold a neutral mid-point. This was so that the scales would align with questions where the response required an indication of frequency, as well as making the analyses more straightforward. For most of the questions, a neutral position was either highly unlikely or not possible. The wording of the Likert-type response levels was developed from a range of typical 5-point response scales used among the academic literature, as detailed by Vagias (2006).

Participants were asked to rate how bad (if at all) they thought exposure to general air pollution was for health, to name any associated adverse effects and asked how frequently they were in situations where adverse effects were thought about. They were also asked how frequently they thought about poor air quality when outdoors at their home, to rate outdoor air quality at their home, how frequently they were concerned about air quality within their homes, to rate the air quality inside their homes, and asked to score the degree to which traffic noise affected them at their homes. Those who were employed were asked the same set of questions in regard to air quality at their workplace. Finally, an extra question on thoughts relating to potential long-term health impacts was asked to those living within 150 m of a major road. The responses to these questions were then coded into variable names for analysis. The exact questions used are given in Table 6.1.

Table 6.1 List of core survey questions and dependent variables used in analyses

Variable	Question	Ordered Response Scale (5-point)
ExpBadHealth	Do you feel that exposure to pollution from traffic, industry and home heating is **bad for human heath in general?**	Not at all to Very Bad
AdverseEffects	Can you name any **adverse health effects** which may be **associated with air pollution**?	None to Four or more
FreqSituations	How often do you find yourself in an **exposure situation** where you **think about the possible effects of air pollution in relation to health**? Do not include pollution from tobacco smoke	Never to Daily
FreqHomeOutdoor	How often do you **find yourself thinking** about the **possible health effects** of air pollution from **outdoor sources**, **while at home?**	Never to Daily
AirHomeOutdoor	How would you rate the overall **cleanliness of the air at your home, while outdoors**?	Very Poor to Excellent
FreqHomeIndoor	How often do you find yourself thinking about the possible health effects of air pollution from **indoor sources**, **while at home**?	Never to Daily
AirHomeInside	How would you rate the overall **cleanliness of the air at your home, while indoors**?	Very Poor to Excellent
TrafficNoiseHome	To what degree **does traffic noise affect you while at home**?	Not a Worry At All to a Major Concern
Live150Health	If you **live within 150 metres of a major road**, what are your perceptions in terms of how that **may or may not influence your health or the health of your family**?	Not a Worry At All to a Major Concern

Door-to-door recruitment was employed primarily due to the need to speak with those limited number of residents who lived just several metres from the highway edge. It was decided that if the mail drop method resulted in a low response rate from those in closest proximity, then we would miss some of the more extreme responses we were interested in and the sample could possibly skew towards those who lived too far away to be affected. A similar mail-out survey of four London suburbs had response rates of just 8.7 - 13% (Day 2006). Therefore, the aim was to recruit 25 participants who lived within the immediate influence (150 m) windward or leeward of the highway, as well as 25 participants who lived further back (> 150 m) at either side of the highway, for each study area (100 in total). In order to ensure responses were not confounded by interference from proximity to other major roads, only quieter parallel roads - often consisting of dead-end streets - were chosen. It was important that the highway remained the main focal point of the interview, so for this reason, few participants were recruited from perpendicular roads. Those outside of the targeted 150 m zone were often one whole block away (~100 m), which resulted in a slight spatial gap in the data. All participants close to the highway lived within 90 m and those further away, between 150 and 500 m.

The primary motivation for choosing two study areas was not to focus on comparing results from the two areas, but to obtain a varied cross-section of society reflected by the varying ethnicities and divergent median income levels. In addition, we wanted to ensure any identified relationships were formed as a result of living near any major highway, as preconceptions of living in such close proximity to New Zealand's busiest road in Otahuhu could possibly exert a stronger influence on responses, than living next to a substantially lesser-trafficked highway elsewhere. Having two study areas also doubled the number of target homes along the highway edge, which would help reassure study success in the event that there was a low willingness to participant.

Residents were door-knocked between the hours of 12:00 midday and 7 pm, Thursdays - Sundays, throughout the month of November, 2011. This was to improve the odds of collecting a more even participant sample group consisting of as many full-time workers as possible, rather than only including stay-at-home parents, the unemployed and the retired. Most surveys took a maximum of 10 - 15 minutes. Some participants asked the interviewer to return another day and some referred friends and family to participate. In keeping these appointments, the total number exceeded the target of 100 by four, hence 104 participants. The semi-structured interview was reviewed and approved by the Human Ethics Committee (HEC 2011/94) at the University of Canterbury before the project commenced.

6.2.3 Analytical techniques

Using satellite imagery (Google Earth 6.0, Google Inc.), the predictor variable 'DistanceFromHighway' was measured as the most direct perpendicular path between each residential building and the edge of the nearest highway lane. Multivariate linear regression was conducted to test the association between ordered response variables (dependent or regressor variables), 'DistanceFromHighway' and measures of income (independent variables). Multivariate testing is a common choice for analysing Likert-type data and has been used in many studies relating to air quality, such as assessing quality of life for asthmatics (Leander et al. 2012; Talreja et al. 2012).It is sometimes viewed as better practice to use ordered logistic regression but the subset of questions used were not designed to be explored to that extent. Question design was not intentionally hierarchical and we were not interested in analysing how well one response

could be predicted by the response to other questions. Prior to running the analyses, the relationship between all regressor variables were tested within a correlation matrix to ensure no pairs were too closely related. There was a moderate-strength relationship (r=0.63) between how serious participants thought air pollution exposure was for health in general and how frequently they thought about exposure situations; the rest were weak (r<0.50). As these questions hold relevance on their own standing, and the correlation was well within the limit of acceptability, both were retained.
The first model run included all of the main variables (Table 6.1), except 'Live150Health', regressed with the independent variables 'DistanceFromHighway', 'PersonalIncome' and 'HouseholdIncome'. As education level was not included in the survey, level of income was used as a surrogate to control for influence on the responses chosen. A second run tested all dependent variables again, including 'Live150Health', but only for 'DistanceFromHighway' and only for participants who lived within the immediate highway corridor (n=54). The purpose was to see if any statistically significant findings within the main model would remain within this close-proximity population subset, over a limited spatial extent of < 90 m. The distributions of residuals from both models were then plotted as histograms and normal probability plots. Normal distribution for Likert-type multiple regression is generally seen as not of vital importance but is worth reviewing for key significant variables (Norman 2010). As the samples sizes were equal, homocedasticity testing e.g., Box's M, was not required.

Although the same question set was repeated for perceptions of air quality at the workplace, no multivariate modelling was applied on this dataset. Primarily this was due to a lack of key interesting independent variables, but also due to a lower number of working survey participants (n=61) and unequal sample sizes as a result of varying work environments; outdoor workers cannot rate indoor air quality at the workplace. The motivation for collecting this data was to compare air quality concerns at the home versus the workplace and basic results were plotted as stacked column charts using Excel (Excel 2010, Microsoft®). Advanced analyses were performed in Statistica (Statistica 10, Statsoft Inc.). Geospatial mapping was done in ArcGIS (ArcGIS 10, ESRI).

Finally, all responses to the open-ended questions were collated, explored for common themes and ranked on a 5-point scale based on sentiment - very negative, slightly negative, neutral, positive and very positive. Some of these narratives are included in the results to build on the ordered response scale analysis and to provide further insight into the reasoning behind the chosen response levels.

6.3 Results and Discussion

6.3.1 Difference between study areas

To compare the two areas, the percentage difference between the mean scores for each question was calculated. The greatest divergence of the means occurred for FreqSituations, TrafficNoiseHome and Live150mHealth, which ranged from 17-19% (~1 response level) higher at Otahuhu. This may have occurred as a result of most of the close-proximity participants in Otahuhu being downwind of the highway whereas 100% of the Mangere Bridge counterparts were situated upwind (no residential buildings downwind). Due to a lack of cases (only 10 upwind at Otahuhu), position relative to predominant wind direction was not included in the analyses and would have required the inclusion of categorical predictors. The rest of the variable means deviated a maximum of 5 - 10%, or .25 - .50 response levels. We acknowledge that including wind direction would have been ideal but feel it is appropriate to analyse these data together within single models; our primary interest was the impact of proximity on perceptions. Further, all participants will be fully aware of how close their house is to the highway but not all will have an understanding of local meteorology.

6.3.2 Overall participant perceptions

Seventy percent of participants felt exposure to general air pollution was somewhat or moderately bad for human health, demonstrating strong awareness within the communities. Not a single respondent felt that air pollution had no impact on health, yet 39% could not name one adverse health effect (Figure 6.3). The frequency level in which they thought about the impacts of poor air quality on health was rather evenly spread, with 23% never thinking about it and 14% reflecting on a daily basis. Almost half (48%) never thought about outdoor air while at home even though 56% rated the air as no better than average. There was slightly less concern about indoor air; no one gave an air quality rating of very poor and 13% described it as excellent compared to only 5% for outdoor air. More than half (54%) were not worried about traffic noise but 14% said it was a moderate or major concern. Of those who lived within the highway corridor, one fifth expressed moderate or major long-term health concerns.

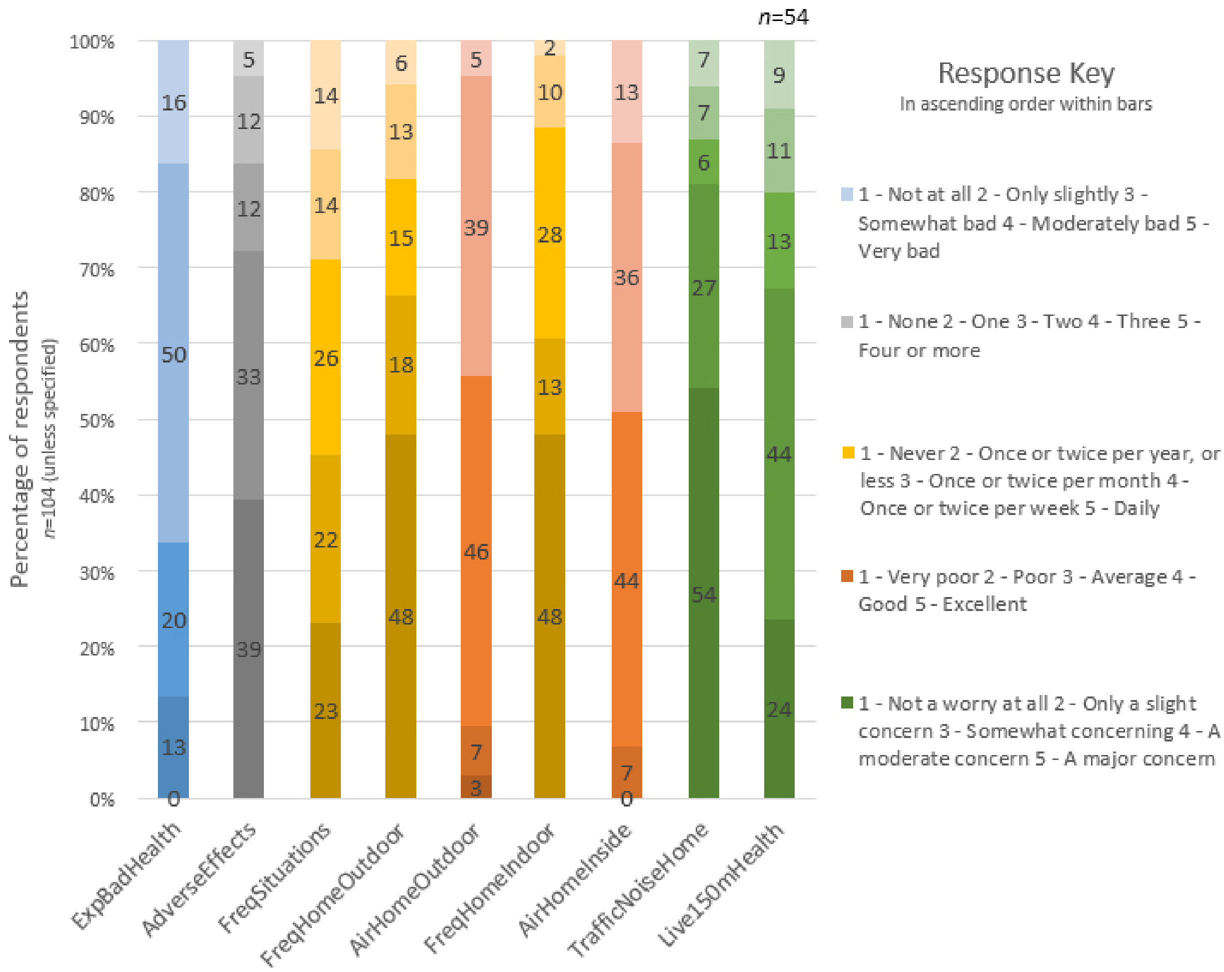

Figure 6.3 Proportion of responses to main study variables: General perceptions and the home environment

Concern at the work environment was much more limited (Figure 6.4). A quarter rated the air outside of their workplace as excellent, suggesting their workplaces were located in better areas than the home or that the perceptions of the locations were more positive. Just 4% conveyed serious concern about poor workplace air quality and four participants stated they had moderate or major concerns about the long-term health implications of working there. These employees worked in labouring jobs with high exposure to paints and solvents.

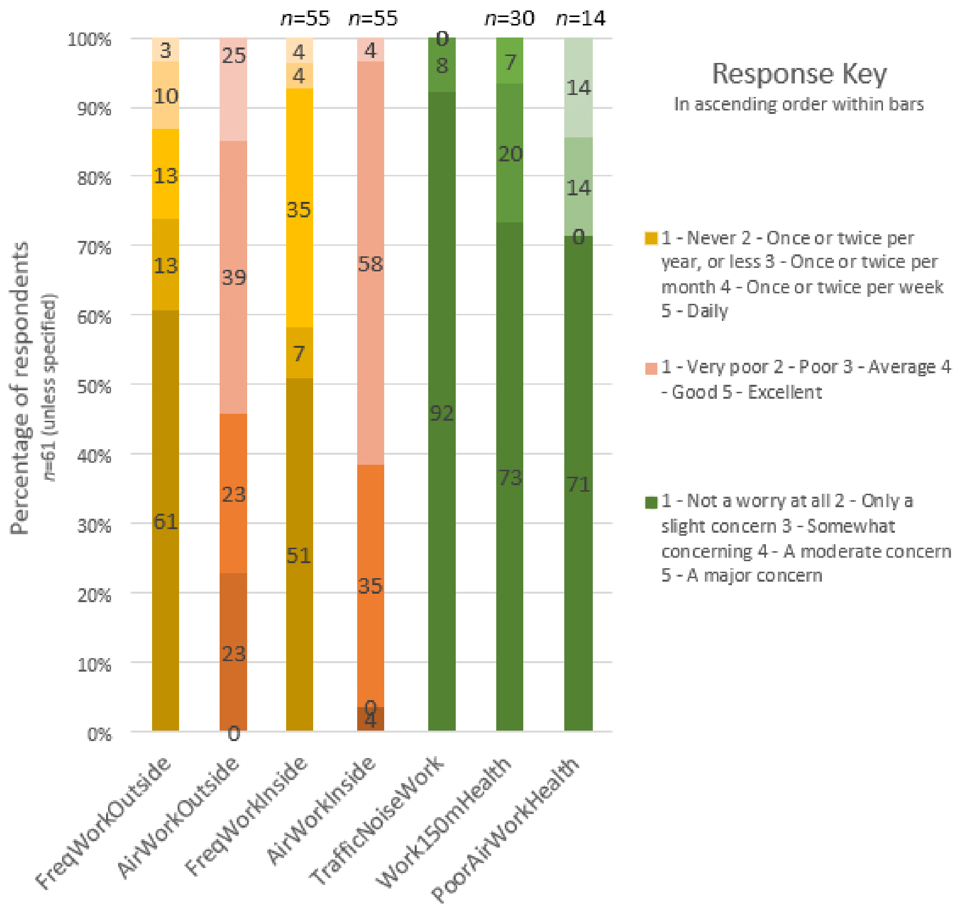

Figure 6.4 Proportion of responses relating to questions about the workplace

6.3.2 Influence of proximity to highway on perceptions

The results of the multivariate regression analysis showed an inverse linear relationship with distance from highway and how bad participants thought exposure was for health (β=-.210, *t*=-2.097, *p*=.039), how many adverse effects they could name (β=-.305, *t*=-3.148, *p*=.002), how frequently it was thought about (both in general and while outdoors at home; β=-.444, *t*=-4.792, *p*<.001, and β=-.208, *t*=-2.066, *p*<.041) and the extent to which traffic noise was a problem (β=-.321, *t*=-3.278, *p*=.001). There was a positive linear relationship between distance from highway and ratings of outdoor air quality (β=.367, *t*=3.864, *p*<.001); in other words, those living a significant distance back were unlikely to provide a poor rating (Table 6.2).

Table 6.2 Multivariate linear regression results for distance from highway and survey response variables (refer to Table 1 for full description of variables)

	Test	Value	F (df, error df)	*p*-value
Intercept	Wilks	0.069	157.311 (8,93)	<0.001
DistanceFromHighway	Wilks	0.703	4.905 (8,93)	<0.001
***n*=104**	**β**	**Std.Err. of β**	**t(95)**	***p*-value**
ExpBadHealth	-0.210	0.100	-2.097	0.039
AdverseEffects	-0.305	0.097	-3.148	0.002
FreqSituations	-0.444	0.093	-4.792	<0.001
FreqHomeOutdoor	-0.208	0.101	-2.066	0.041
AirHomeOutdoor	0.367	0.095	3.864	<0.001
FreqHomeIndoor	-0.068	0.102	-0.667	0.507
AirHomeInside	0.065	0.100	0.653	0.515
TrafficNoiseHome	-0.321	0.098	-3.278	0.001

With the exception of a negative association between household income and number of adverse effects named (β=-.262*, t*=-2.394, *p*=.019, Table 6.3), no other statistically significant findings were identified (including the test against personal income). As incomes increased with distance from highway (Figure 6.2), it is possible that residents living further back have less impetus to reflect on detrimental effects. However, due to the lack of any other significant findings across both measure of income models, we conclude that no meaningful associations can be drawn between income and attitudes from this dataset, within this spatial extent (≤ 482 m). Widening our participant recruitment to include the least deprived census meshblocks in the outer limits of the Mangere Bridge study area may have improved associations, but at a distance of 600 m+ upwind, the highway is of very limited relevance.

Table 6.3 Multivariate linear regression results for household income and survey response variables (refer to Table 1 for full description of variables)

	Test	Value	F (df, error df)	*p*-value
Intercept	Wilks	0.069	157.311 (8,93)	<0.001
HouseholdIncome	Wilks	0.854	1.984 (8,93)	0.056
***n*=104**	**β**	**Std.Err. of β**	**t(95)**	***p*-value**
ExpBadHealth	-0.183	0.113	-1.620	0.108
AdverseEffects	-0.262	0.109	-2.394	0.019
FreqSituations	-0.037	0.105	-0.355	0.723
FreqHomeOutdoor	-0.170	0.114	-1.491	0.139
AirHomeOutdoor	-0.036	0.108	-0.331	0.741
FreqHomeIndoor	-0.048	0.116	-0.414	0.679
AirHomeInside	-0.165	0.113	-1.458	0.148
TrafficNoiseHome	-0.095	0.111	-0.858	0.393

Of greater interest were the significant findings for highway proximity (Table 6.2) and whether any associations would remain when tested for the population subset living directly alongside the highway (< 150 m). Not only did outdoor air quality ratings improve with distance from highway for the whole study group, but there was also a positive linear effect across the highway corridor (β=.496, *t*=2.596, *p*=.013, Table 6.4). Furthermore, residents situated closer towards the 100 m point gave more positive ratings of indoor air than those living within the first 40 m (β=.310, *t*=2.021, *p*=.049, Table 6.4). Comparisons between indoor and outdoor air ratings - for the whole study group and for the highway corridor group - are illustrated by Figure 6.5. Across the complete study population, there was no trend evident for indoor air ratings and distance (Figure 6.5b). This suggests that negative perceptions of the influence of the highway have a more limited spatial extent for the indoor environment than for outdoors. This is in line with the perception that the indoor environment is better protected (only 12% thought about it on a regular basis) and is able to be controlled; smoke, odours and noise can largely be shut out and eliminated.

Table 6.4 Multivariate linear regression results for distance from highway: participants living within the immediate highway corridor (refer to Table 1 for full description of variables)

n= 54 R= .562 R^2= .317 Adjusted R^2= .180 $F_{9,45}$=2.3197 p=.030 Std.Error of estimate: 18.154						
	β*	**Std.Err. of β***	**β**	**Std.Err. - of β**	**t(95)**	***p*-value**
Intercept			-43.832	24.248	-1.808	0.077
ExpBadHealth	0.125	0.162	2.824	3.663	0.771	0.445
AdverseEffects	0.051	0.135	0.806	2.128	0.379	0.706
FreqSituations	0.092	0.175	1.068	2.021	0.528	0.600
FreqHomeOutdoor	0.454	0.222	4.785	2.338	2.047	0.047
AirHomeOutdoor	0.496	0.191	11.272	4.342	2.596	0.013
FreqHomeIndoor	0.007	0.175	0.081	1.970	0.041	0.968
AirHomeInside	0.310	0.154	8.163	4.038	2.021	0.049
Live150Health	-0.095	0.154	-1.783	2.900	-0.615	0.542
TrafficNoiseHome	-0.175	0.155	-3.889	3.444	-1.129	0.265

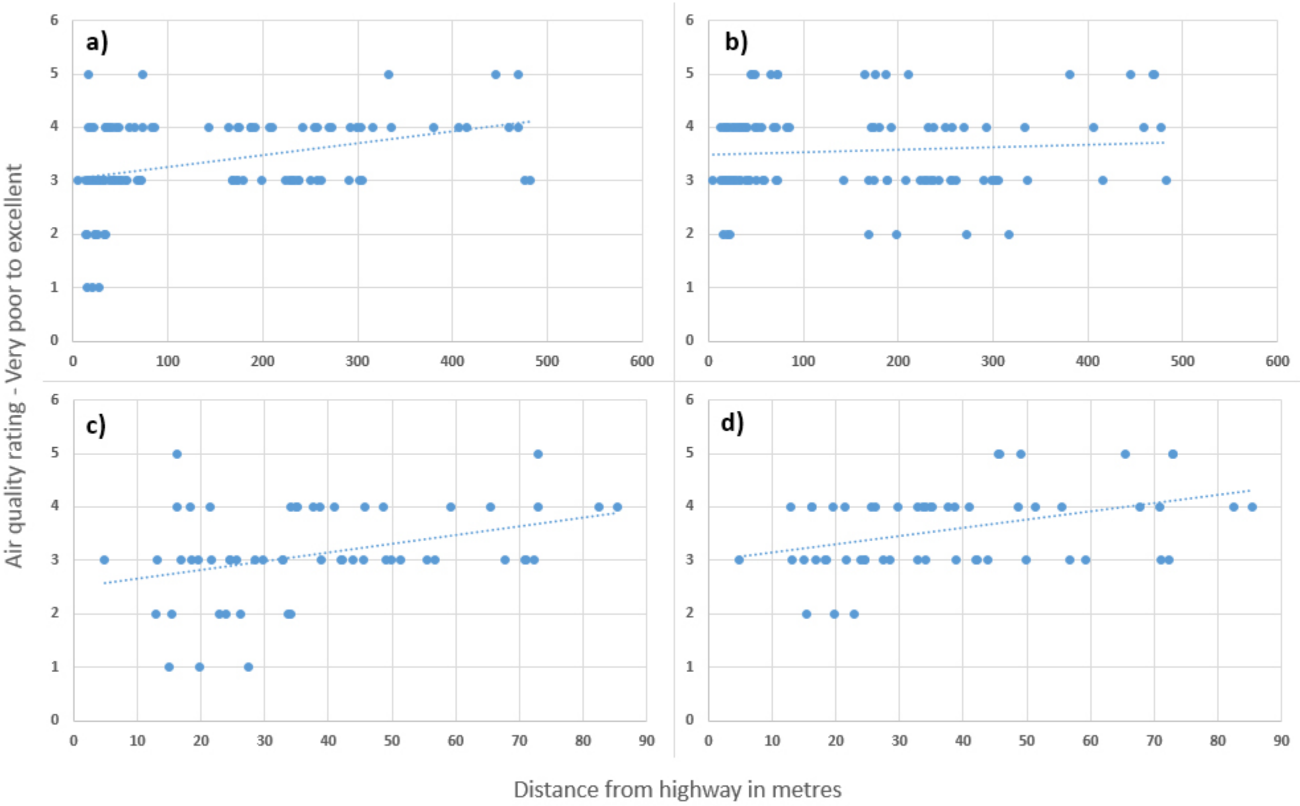

Figure 6.5 Scatterplots of participant air quality ratings for: all participants a) outdoors b) indoors; participants living within 150 m of highway c) outdoors d) indoors. All except for b) were significant at *p*<0.05

6.3.3 Level of concern for within-corridor residents

Building on the previous section, many residents elaborated with both positive and negative discussion points following the ordered-response ratings. Those living at the edge of the study extent made few comments of interest, hence the focus on feelings at the highway fringe. Some common topics were raised and selected quotes are provided for emphasis (Table 6.5). It's important to note that participants were not prompted with suggestions e.g. smell, soot, but brought these issues up voluntarily, making them more accurate representations of what they personally felt strongest about. Excluding those related to work, 113 comments were made, giving an average of two per person, and some comments encompassed several issues. Of 124 points identified, 23% were positive and the remainder were negative.

Table 6.5 List and frequency of all negative and positive aspects of living within a highway corridor

Negative points	Frequency raised	Percentage of all points raised
Emissions - smoke or soot	~~////~~ ~~////~~ ///	10.5%
Emissions - smell or taste (fumes)	~~////~~ ~~////~~ /	8.9%
Emissions as a barrier to daily activity	///	2.4%
Road dust and dust re-suspension	~~////~~ ////	7.3%
Accumulation of dust or other material (inside)	~~////~~ /	4.8%
Thickness of the air (denser than elsewhere)	/	0.8%
Noise from traffic	////	3.2%
Indoor emissions sources (fire or gas)	////	3.2%
Lack of home ventilation system	//	1.6%
Industrial - smoke	/	0.8%
Industrial - smell or taste	//	1.6%
Illegal rubbish fires	/	0.8%
Odour from sewage ponds	//	1.6%
Exacerbation of asthma	~~////~~ ~~////~~ ~~////~~	12.1%
Exacerbation of other health ailment or allergy	///	2.4%
Concern for health of children	~~////~~ ~~////~~ /	8.9%
Concern for health of other family member	~~////~~ ~~////~~	8.1%
Concern for health of pets	/	0.8%
Positive points	**Frequency raised**	**Percentage of all points raised**
Accessibility (due to location of home)	//	1.6%
Cheaper housing	//	1.6%
Good home ventilation system	//	1.6%
Indoor air is better than outdoors	~~////~~ ~~////~~ //	9.7%
Dispersion from wind	~~////~~ ///	6.5%
Other environmental protection - fences, plants	//	1.6%

Nearly 80% of the entire study group demonstrated awareness that poor air quality was harmful in some way and 62% correctly identified at least one associated adverse health effect. This is considerably higher than the same figures reported for a similar study in Birmingham, UK, which were 56% and 45%, respectively (Bickerstaff & Walker 2001). It is somewhat problematic to compare statistical outcomes due to the targeted nature of our study population and smaller sample size, where stronger opinions are likely to be more concentrated. However, similarities between some of the open-ended responses and the overall findings are readily observed. Bickerstaff & Walker (2001) found that while approximately two thirds expressed some degree of concern for health, most of the concern lay with family members rather than for oneself. Three quarters of our roadside corridor population stated they had concerns for long-term health, but only two explicitly spoke of concern for themselves.

> *"I'm on a kidney dialysis machine and I also have a bad heart, so it's a concern for me. Our asthma and coughs are a problem* [mine and my wife's]. *I need exercise - we have to go out walking but we gotta get away from the motorway. It's not healthy in this community. We have to drive away to a park area. Sometimes I take a walk to the letterbox but I can't go much further than that."* [around here] ~ Resident of 4 years, 22 m upwind, Otahuhu

Although concern for children was undoubtedly the strongest (8.9% of all issues raised), there was almost an equal number of inferences made to the health of other adults (8.1%) - usually a partner or close family member living in the immediate household.

> *"I've noticed the kids' asthma is much worse since we moved here from a quiet area. They have to visit the doctor more frequently. Before they went hardly ever, now they have to go once a fortnight. They also need to use the ventilator since moving but didn't use it before."* [All three kids are asthmatic]. Resident of 1 year, 45 m upwind, Mangere Bridge

> *"Sometimes I feel like shifting away because it's really important for the health of my kids. Three of my kids have asthma and we have no family history of it. Their schools and day centres are close to motorways too."* ~ Resident of 13 years, 56 m upwind, Otahuhu

The possible causative link to asthma was identified during several interviews and asthma exacerbation was the most common of all complaints (Table 6.5). One respondent was particularly concerned about dust levels and fumes affecting her children.

> *"My daughter's asthma, which I believe is purely environmental. I haven't taken her to the doctor yet but I will. Both of the kids have exacerbated allergies since we moved here* [from Christchurch]. *It gets very dusty in here* [due to re-suspension from the highway]. *We have to clean the house of dust a few times a week - we're sick and tired of it. It's worse on this side of the motorway and usually comes from the west, I think. When I go outside I can smell it* [fumes from traffic]. *It keeps going 24 hours per day. I'd rather just close all my doors. We didn't even think like that when we first stayed here - being so close to the motorway and all that. Inside air is good apart from dusty days."* ~ Resident of 9 months, 15 m downwind, Otahuhu

Research involving qualitative interviews with ~50 residents in London also found asthma was the most commonly identified health condition and that it was thought to possibly be a direct outcome of air pollution exposure. In addition, respondents mentioned bronchitis, emphysema, cystic fibrosis, low birth weight, heart disease, memory damage, and several allergies(Day 2006). Our 54 highway corridor residents also demonstrated excellent knowledge, naming a total of twenty different health effects including eczema, skin cancer, lung cancer, cardiovascular disease, stroke, brain damage and more, all of which have been linked to exhaust emissions exposure (Boffetta et al. 1997; Gan et al. 2010; Lee et al. 2008; Raaschou-Nielsen et al. 2011; Ranft et al. 2009; Wilker et al. 2013). The regression slope for number of adverse effects named (β=-.305, t=-3.148, p=.002) and the fact that measures of income were not significantly associated with attitudes and perceptions, lends weight to proximity being a stronger predictor of health effects knowledge, than education. These findings mirror those of an industrial pollution perception survey of 2744 participants in Northeast England (Howel et al. 2003). Nonetheless, almost one third (32%) of our highway corridor residents could not name a single health effect and this grew to 39% when extended to the whole study population. Evidently, environmental health holds more importance for health-afflicted individuals, those closest to the source and those with families (Bickerstaff & Walker 2001; Howel et al. 2003).

Some concerns were only slightly negative. One interesting finding was that several participants perceived that the traffic situation would only get worse [and pollution would increase].

> *"The possible health effects are a bit of a concern. As we get more cars, it's only going to get worse."* ~ Resident of 7 years, 25 m downwind, Otahuhu

> *"It's a slight worry as there will only be more cars on the road in the future. No one here has asthma or anything like that."* ~ Resident of 22 years, 38 m upwind, Otahuhu

Others were more philosophical, balancing out the advantages and potential drawbacks.

> *"Short-term, the benefits outweigh the risks. We have a huge yard, plenty of space to park the cars etc. There could be a long-term effect. We plan to move when the opportunity arises."* ~ Resident of 1 year, 20 m downwind, Otahuhu

> *"I'm here because it's convenient. It's handy. I bought it cheap. Noise is more concerning than air."* ~ Resident of 13 years, 72 m upwind, Otahuhu

Numerous participants did not care about the subject and only made brief comments.

> *"The kids are doing well so I don't think I should be concerned."* ~ Resident of 9 years, 16 m upwind, Otahuhu

> *"It doesn't bother me particularly. I'm more worried about my partner smoking."* ~ Resident of 6 weeks, 22 m upwind, Mangere Bridge

> *"Don't care. Don't really mind."* ~ Resident of 1 year, Mangere Bridge

Several participants accurately surmised that local meteorology played a strong role in mitigating highway emissions impacts and one spoke of positively modifying his home environment.

> *"I'd say that in this geographical location, it's not an issue. Petrol was already unleaded by the time the motorway was put in. I've lived in much worse places overseas! We get the prevailing westerly with fresh air coming in from the harbour. So it's quite good here - we're lucky."* ~ Resident of 45 years, 73 m upwind, Mangere Bridge

> *"I've grown up here and I made the choice to stay. I've become desensitised. I've got a lot of plants and I'm doing the best I can. I also built a large fence recently. It changes the environment around me. The air's always moving around here. We get the equinox and the westerly winds."* ~ Resident of 5 years, 35 m downwind, Otahuhu

Some spoken responses exuded much enthusiasm and presented the highway in a positive light.

> *"Neither one of us suffers from breathing difficulties - nor do our kids. Long-term, we've been good as gold. Never really considered it. We lived on a busy road before this one too."* [Great South Road] ~ Residents of 48 years, 66 m downwind, Otahuhu

> *"It doesn't worry me. I'm 85 and I'm doing just fine. After they put the motorway in, I could get to town so much quicker. It's great."* ~ Resident of 60 years, 30 m downwind, Otahuhu

A recent study of 1225 residents living with 1000 m of busy highways in the Netherlands found that 85% reported being satisfied living next to a highway. Likert-type scale question results showed only modest annoyance in regard to air and noise pollution, and a very high level of satisfaction for location of home and accessibility (Hamersma et al. 2014). Respondents were divided into two groups - those at 0 - 300 and those at 300 - 100 m. surprisingly, although noise was perceived to be a greater problem by the close-proximity group, there was no significant difference for air pollution. However, no information was provided on exactly how close participant's homes were and if there were any mitigating features such as green belts or noise barriers. Undoubtedly there was a high level of satisfaction expressed by most of our participants but also a very strong desire to move away from the area, among a select few.
Only two participants mentioned industrial air pollution, reflecting the lack of immediate nearby sources and dominance of the motorway as the primary local source. One person gave a detailed description of their thoughts on local industrial influences, compared with the motorway right at the edge of their backyard.

> *"Outside I'm thinking about it a lot as we get all the crap from the Onehunga industrial zone when the conditions are right i.e. easterly winds. Over there they have a cogen plant* [cogeneration plant]*, which emits steam and a mixture of other things. There's also ACI glass and Tasman fibreglass - you can see the plumes from certain industries. There are numerous discharges to air over there - both above and below board. You've got to wonder what's coming out of some of these places as the smells can be quite strange. I've also noticed a brown haze down the motorway on occasion. I only ever think about it getting indoors when people light rubbish fires in the right wind conditions* [can smell it]*. Compared to the interchange, it's much better at the motorway here as the traffic is quite free-flowing."* ~ Resident of 7 years, 16 m upwind, Mangere Bridge

Finally, we present an example of how qualitative data can be presented geospatially to highlight diverging perceptions between neighbours who are all exposed to the same major emissions source (Figure 6.6). Such a tool is useful for highlighting the degree to which affected individuals are impacted. Despite the scientific consensus that those living downwind are greater exposed to long-term environmental harms, not everyone is aware of this and only certain groups show moderate to major concern. Although we did not request age data, there was a clear impression that long-term residents, the elderly and the childless were the least concerned (also evident in Figure 6.6). Similarly, those who felt positive towards automobile use exhibited greater enthusiasm for their home location, as previously reported by international research (Hamersma et al. 2014).

Figure 6.6 A geospatial representation of concerns about living in close proximity to a major highway in Otahuhu

6.4 Conclusions

This study provided substantial insight into resident's perceptions and understandings of the influence of highway traffic on local air quality. Most international research of similar nature is confined to perceptions of industrial pollution, which is typically a more obvious threat than vehicular emissions. Plumes of smoke from nearby industrial stacks are likely to invoke more profound feelings than exhaust emissions, which may only be noticeable under particular atmospheric conditions. Furthermore, most residents have a beneficial relationship with vehicles and roadways while connections to nearby industry are less direct, with the exception of those employed to work there. This makes comparison to the industrial pollution literature somewhat problematic, although some parallels are evident.
The influence of proximity was clear. With increasing distance from the highway, participants thought about traffic pollution less often, demonstrated less knowledge about associated health effects and rated both their indoor and outdoor air quality better. Overall though, knowledge of health effects was very good and agreed with current scientific consensus. Several residents expressed that local highway emissions restricted their activities by keeping them indoors. Limiting the intake of outdoor air by controlling doors and windows in certain parts of the house was a common theme within the open-ended answers. Dust infiltration was a serious problem for those nearest to the roadway, closely followed by noise. Much concern was expressed for children's health and the health of other adults and some felt the traffic situation would get worse. Long-term residents and the elderly were the least concerned.

The spatial assessment of perceptions in our study provides new understandings at a finer scale than previous studies. Although the sample size is limited, there is some indication of the separation required to achieve a better sense of wellbeing; the very worst ratings of air quality (indoors & out) were given only by those who lived within 40 m of the highways. The closer to the highway, the more air pollution was thought about and the worse it was perceived to affect health, yet attitudes improved over a very short distance and remained average or better, further afield. We have demonstrated that, in addition to the physical exposure benefits, there may also be a degree of quantifiable psychological benefit gained from a limited-distance separation from the highway. Such a benefit has significant potential to transform into added health outcomes, including increased time spent outdoors, greater physical activity and improved neighbourhood sociability. Future work should assess the possible benefit of mitigation such as green belts and noise walls on air pollution perceptions. In the interim, this research may help inform land-use policy decisions and social policy on the placement of sensitive groups within roadside communities.

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References

Barros, N, Fontes, T, Silva, MP & Manso, MC 2013, 'How wide should be the adjacent area to an urban motorway to prevent potential health impacts from traffic emissions?', *Transportation Research Part A: Policy and Practice,* vol. 50, pp. 113-28.

Bickerstaff, K & Walker, G 2001, 'Public understandings of air pollution: the 'localisation' of environmental risk ', *Global Environmental Change,* vol. 11, pp. 133-45.

Boffetta, P, Jourenkova, N & Gustavsson, P 1997, 'Cancer risk from occupational and environmental exposure to polycyclic aromatic hydrocarbons', *Cancer Causes Control,* vol. 8, no. 3, pp. 444-72.

Brereton, F, Clinch, JP & Ferreira, S 2008, 'Happiness, geography and the environment', *Ecological Economics,* vol. 65, no. 2, pp. 386-96.

Carrier, M, Apparicio, P, Séguin, A-M & Crouse, D 2014a, 'Ambient air pollution concentration in Montreal and environmental equity: Are children at risk at school?', *Case Studies on Transport Policy*.

Carrier, M, Apparicio, P, Séguin, A-M & Crouse, D 2014b, 'The application of three methods to measure the statistical association between different social groups and the concentration of air pollutants in Montreal: A case of environmental equity', *Transportation Research Part D: Transport and Environment,* vol. 30, no. 0, pp. 38-52.

Clark, NA, Demers, PA, Karr, CJ, Koehoorn, M, Lencar, C, Tamburic, L & Brauer, M 2010, 'Effect of early life exposure to air pollution on development of childhood asthma', *Environmental Health Perspectives,* vol. 118, no. 2, pp. 284-90.

Day, RJ 2006, 'Traffic-related air pollution and perceived health risk: Lay assessment of an everyday hazard', *Health, Risk & Society,* vol. 8, no. 3, pp. 305-22.

Evans, KA, Halterman, JS, Hopke, PK, Fagnano, M & Rich, DQ 2014, 'Increased ultrafine particles and carbon monoxide concentrations are associated with asthma exacerbation among urban children', *Environmental Research,* vol. 129, pp. 11-9.

Fuller, CH, Brugge, D, Williams, PL, Mittleman, MA, Durant, JL & Spengler, JD 2012, 'Estimation of ultrafine particle concentrations at near-highway residences using data from local and central monitors', *Atmospheric Environment,* vol. 57, pp. 257-65.

Fuller, CH, Brugge, D, Williams, PL, Mittleman, MA, Lane, K, Durant, JL & Spengler, JD 2013, 'Indoor and outdoor measurements of particle number concentration in near-highway homes', *Journal of Exposure Science & Environmental Epidemiology,* vol. 23, no. 5, pp. 506-12.

Gan, WQ, Tamburic, L, Davies, HW, Demers, PA, Koehoorn, M & Brauer, M 2010, 'Changes in residential proximity to road traffic and the risk of death from coronary heart disease', *Epidemiology,* vol. 21, no. 5, pp. 642-9.

Hamersma, M, Tillema, T, Sussman, J & Arts, J 2014, 'Residential satisfaction close to highways: The impact of accessibility, nuisances and highway adjustment projects', *Transportation Research Part A: Policy and Practice,* vol. 59, no. 0, pp. 106-21.

Houston, D, Li, W & Wu, J 2013, 'Disparities in exposure to automobile and truck traffic and vehicle emissions near the Los Angeles–Long Beach port complex'. American Journal of Public Health, Published online ahead of print, pp. e1-e9.

Howel, D, Moffatt, S, Bush, J, Dunn, C & Prince, H 2003, 'Public views on the links between air pollution and health in Northeast England', *Environmental Research,* vol. 91, pp. 163 - 71.

Hu, S, Fruin, S, Kozawa, K, Mara, S, Paulson, SE & Winer, AM 2009, 'A wide area of air pollutant impact downwind of a freeway during pre-sunrise hours', *Atmospheric Environment,* vol. 43, no. 16, pp. 2541-9.

Karner, AA, Eisinger, DS & Niemeier, DA 2010, 'Near-roadway air quality: synthesizing the findings from real-world data', *Environmental Science & Technology,* vol. 44, no. 14, pp. 5334-44.

Kim, JJ, Smorodinsky, S, Lipsett, M, Singer, BC, Hodgson, AT & Ostro, B 2004, 'Traffic-related Air Pollution near Busy Roads: The East Bay Children's Respiratory Health Study', *Am. J. Respir. Crit. Care Med.,* vol. 170, no. 5, pp. 520-6.

Leander, M, Lampa, E, Janson, C, Svärdsudd, K, Uddenfeldt, M & Rask-Andersen, A 2012, 'Determinants for a low health-related quality of life in asthmatics', *Upsala Journal of Medical Sciences,* vol. 117, no. 1, pp. 57-66.

Lee, G, You, S, Ritchie, SG, Saphores, JD, Sangkapichai, M & Jayakrishnan, R 2009, 'Environmental impacts of a major freight corridor', in *Transportation Research Record*, pp. 119-28.

Lee, SJ, Hajat, S, Steer, PJ & Filippi, V 2008, 'A time-series analysis of any short-term effects of meteorological and air pollution factors on preterm births in London, UK', *Environmental Research,* vol. 106, no. 2, pp. 185-94.

Longley, ID, Kingham, S, Dirks, K, Somervell, E, Pattinson, W & Elangasinghe, MA 2013, *Research Report 516: Detailed observations and validated modelling of the impact of traffic on the air quality of roadside communities*, New Zealand Transport Agency, Wellington.

Marshall, JD, Swor, KR & Nguyen, NP 2014, 'Prioritizing Environmental Justice and Equality: Diesel Emissions in Southern California', *Environmental Science & Technology,* vol. 48, no. 7, pp. 4063-8. Retrieved 2014/08/09, from

Meng, Y-Y, Wilhelm, M, Rull, RP, English, P, Nathan, S & Ritz, B 2008, 'Are Frequent Asthma Symptoms Among Low-Income Individuals Related to Heavy Traffic Near Homes, Vulnerabilities, or Both?', *Annals of Epidemiology,* vol. 18, no. 5, pp. 343-50.

Molitor, J, Su, JG, Molitor, N-T, Rubio, VG, Richardson, S, Hastie, D, Morello-Frosch, R & Jerrett, M 2011, 'Identifying Vulnerable Populations through an Examination of the Association Between

Multipollutant Profiles and Poverty', *Environmental Science & Technology,* vol. 45, no. 18, pp. 7754-60.

Norman, G 2010, 'Likert scales, levels of measurement and the "laws" of statistics', *Advances in Health Sciences Education,* vol. 15, no. 5, pp. 625-32.

Pattinson, W, Longley, I & Kingham, S 2014, 'Using mobile monitoring to visualise diurnal variation of traffic pollutants across two near-highway neighbourhoods', *Atmospheric Environment,* vol. 94, pp. 782-92.

Patton, AP, Collins, C, Naumova, EN, Zamore, W, Brugge, D & Durant, JL 2014, 'An Hourly Regression Model for Ultrafine Particles in a Near-Highway Urban Area', *Environmental Science & Technology,* vol. 48, no. 6, pp. 3272-80.

Raaschou-Nielsen, O, Andersen, ZJ, Hvidberg, M, Jensen, SS, Ketzel, M, Sorensen, M, Loft, S, Overvad, K & Tjonneland, A 2011, 'Lung cancer incidence and long-term exposure to air pollution from traffic', *Environmental Health Perspectives,* vol. 119, no. 6, pp. 860-5.

Ranft, U, Schikowski, T, Sugiri, D, Krutmann, J & Krämer, U 2009, 'Long-term exposure to traffic-related particulate matter impairs cognitive function in the elderly', *Environmental Research,* vol. 109, no. 8, pp. 1004-11.

Riley, S, Wallace, J & Nair, P 2012, 'Proximity to major roadways is a risk factor for airway hyper-responsiveness in adults', *Canadian Respiratory Journal,* vol. 19, no. 2, pp. 89-95.

Rowangould, GM 2013, 'A census of the US near-roadway population: Public health and environmental justice considerations', *Transportation Research Part D: Transport and Environment,* vol. 25, pp. 59-67.

Salmond, C, Crampton, P & Atkinson, J 2007, *NZDep2006 Index of Deprivation*, Department of Public Health, University of Otago, Wellington.

Sørensen, M, Andersen, ZJ, Nordsborg, RB, Jensen, SS, Lillelund, KG, Beelen, R, Schmidt, EB, Tjønneland, A, Overvad, K & Raaschou-Nielsen, O 2012, 'Road Traffic Noise and Incident Myocardial Infarction: A Prospective Cohort Study', *PLoS One,* vol. 7, no. 6, p. e39283.

Statistics New Zealand 2009, *Mapping Trends in the Auckland Region*, Statistics New Zealand Wellington.

Statistics New Zealand 2013a, *2013 Census*, Statistics New Zealand Wellington.

Statistics New Zealand 2013b, *QuickStats About Mangere Bridge* Statistics New Zealand, Wellington.

Talreja, N, Soubani, AO, Sherwin, RL & Baptist, AP 2012, 'Modifiable factors associated with severe asthma exacerbations in urban patients', *Annals of Allergy, Asthma & Immunology,* vol. 109, no. 2, pp. 128-32.

Vagias, W 2006, *Likert-type scale response anchors*, Clemson International Institute for Tourism & Research Development, Department of Parks, Recreation and Tourism Management, Clemson University, Clemson.

Volk, HE, Hertz-Picciotto, I, Delwiche, L, Lurmann, F & McConnell, R 2011, 'Residential proximity to freeways and autism in the CHARGE study', *Environmental Health Perspectives,* vol. 119, no. 6, pp. 873-7.

Wilhelm, M, Ghosh, J, Su, J, Cockburn, M, Jerrett, M & Ritz, B 2012, 'Traffic-related Air toxics and term Low birth weight in Los angeles county, california', *Env Health Perspect,* vol. 120, pp. 132 - 8.

Wilker, EH, Mostofsky, E, Lue, S-H, Gold, D, Schwartz, J, Wellenius, GA & Mittleman, MA 2013, 'Residential Proximity to High-Traffic Roadways and Poststroke Mortality', *Journal of Stroke and Cerebrovascular Diseases,* vol. 22, no. 8, pp. e366-e72.

7. Chapter Seven: Conclusions

This work has sought to contribute towards a few current knowledge gaps in the science of near-highway human exposure to traffic emissions. Chapter two reviewed 106 peer-reviewed articles and high quality theses from 1977 - 2014, which helped to narrow down the focus.

Chapter three makes a valuable contribution to the science by providing one of the only long-term near-highway monitoring studies featuring at least three stations to measure gradients or assess upwind versus downwind, close-to-highway and away-from-highway, diurnal variation. Concentrations of UFPs, NO_x, CO and PM_{10} , averaged every 10 minutes for 92 days provided a richer dataset than most previous near-highway monitoring programs. The overall mean decrease of ~40 - 60% (apart from PM_{10}) by 150 m is not as sharp as reported by short-term monitoring (~65 - 95% for UFPs and CO, depending on season), but is a steeper decline than found by year-long monitoring of approximately 30% for NO_x and CO (Kimbrough et al. 2013; Zhu et al. 2004). Better understandings of the long-term exposure situation help to inform environmental injustice and population health assessments. This chapter also provided a unique, local-scale insight into possible exposure inequity at a finer spatial scale than any previous study. Small census units just a few hundred square metres in size were used to assess levels of socioeconomic deprivation for highway corridor populations. It was found that highway proximity was associated with the most heavily deprived social classes and that income levels increased with distance. Unlike most international studies, there was no indication of environmental injustice by ethnicity, with populations closest to the highways evenly comprised of approximately 50% European and 50% non-European. This is only the second piece of traffic-related environmental justice research for New Zealand and supplies the basis for a wider-scale analysis of Auckland city and beyond.

Chapter four makes a novel contribution to the spatial saturation research by using a non-emitting vehicle (bicycle) to map every street and publicly accessible pathway across two highway neighbourhoods. Unlike previous mobile monitoring conducted during rush hour periods, this sampling consisted of repeated runs during four time periods - on the cusp of the morning rush, at midday when traffic levels dip, during the early evening rush, and very late at night. Concentrations were mapped by time of day to visualise diurnal fluctuations in the spatial extent of roadway emissions throughout the communities; a unique approach to addressing an obvious literature gap. Comparisons in percentage decay agreed well with fixed-station data for the same time periods and the mobile monitoring was able to extend this in finding concentrations of UFPs did not reach background level until ~650 m during the early morning and late evening periods. Further, the influence of the highway was adequately dispersed from midday to early evening, with elevated concentrations limited to more sheltered, street canyon areas. This is the first time a bicycle has been used to systematically map a residential highway zone and the results help advance the understandings of the diurnal variation of roadway impacts.

Chapter five utilised the fixed-station monitoring, plus data from out-of-area monitors, as the primary inputs into an ambient multi-pollutant personal exposure model. The model used was APEX, a US-EPA population-based stochastic model which is well-regarded throughout the literature and is continually being improved. Instead of modelling exposures for a large number of random individual profiles living throughout a city (population modelling), the stochastic aspect was removed so that the exposures of specific individuals within a community could be simulated using time-activity information and the geographic co-ordinates of their home and work locations. The time-activity data accurately reflected behaviours in the community, as it was provided by local residents. Exposure for the entire month of July, 2010, was simulated using the residents actual home locations. The impact of proximity to highway was subsequently explored by placing their home locations in different positions relative to the highway. The results give an indication of which persons (dependent on occupation) would receive the most ambient exposure benefits of a separation buffer between the highway and place of residence. This is an unusual, novel application of a personal exposure model which contributes to a relevant, current-day literature gap. The most recent studies to date (Barros et al. 2013) are recommending a separation buffer of at least 100 m but there is little understanding as to whom would actually benefit the most by receiving a quantifiable reduction in long-term exposure. Assuming relatively fast air exchange rates (measured in a local home), meaning the indoor environment is prone to heavy ambient infiltration, total mean ambient exposure (excludes all indoor sources) for the entire group simulated would be up to 70% higher if they lived within the first 50 m of the road, instead of 150 m downwind. Those who already had high daily exposures - people who spent a lot of time at home, outdoors, as well drivers and outdoor labourers - received a greater benefit but the effect was modest (about 5% greater reduction than others). However, mean exposure variation between those in different occupational groups living in the 50 - 150 m zone, diverged by a factor of eight. This clearly highlights the impact of living in such extreme proximity, in the context of the work one carries out. This work also suggests that the elderly, who enjoy spending a lot of time outdoors gardening, would benefit by being further away more than other groups. Although children were not included in the model, it follows that this vulnerable group would also receive greater benefits by reduced exposures when playing outside at or near their homes. Overall, this modelling work lends support to improving policy and planning so that a highway corridor buffer is required for new residential development and sensitive development such as retirement villages.

Chapter six also makes a distinctive contribution to a limited literature base by looking at highway proximity as a function of attitudes and perceptions towards roadway emissions. It was found that distance-from-highway has a strong inverse linear effect on concern for health impacts and noise levels, with the greatest concern expressed by residents residing within the first 40 m. Qualitative discussion revealed a high degree of concern for children's respiratory health and for those with pre-existing illness. Discussion also suggested that living near a highway is unsuitable for those suffering from chronic illness as perceived poor air quality inhibits the desire to partake in outdoor activities. Despite these negative findings, some positive points were raised; several residents stated they were very happy with the accessibility and cheaper housing offered by the area.

Collectively, this multi-layer scientific investigation makes for an unusually comprehensive study of air quality impacts on a local community. Overall, the findings suggest elevated concentrations are only an issue downwind of the highway during low wind speed, cool temperature periods, and that the extent is limited to a few hundred metres. However, long-term monitoring indicates that there is an elevated downwind exposure belt adjacent to highways and this could negatively impact the local population. Although physical health effects were not measured, it is clear from the views expressed in chapter six that the highway impacts both physical and mental health. The infiltration of fumes, dust and noise twenty-four hours per day affects the psychological health of mothers of young children and family members of the chronically ill. Physical health is impacted by reduced outdoor activity due to perceived risk. It is also likely that living in this area exacerbates asthma issues, especially for children who may also attend near-highway schools. It is hoped that the work presented in this thesis helps to inform future decisions surrounding planning, land use and social policy. At the very least, the placement of sensitive individuals and groups should be thoughtfully considered.

References

Barros, N, Fontes, T, Silva, MP & Manso, MC 2013, 'How wide should be the adjacent area to an urban motorway to prevent potential health impacts from traffic emissions?', *Transportation Research Part A: Policy and Practice,* vol. 50, pp. 113-28.

Kimbrough, S, Baldauf, R, Hagler, GW, Shores, R, Mitchell, W, Whitaker, D, Croghan, C & Vallero, D 2013, 'Long-term continuous measurement of near-road air pollution in Las Vegas: seasonal variability in traffic emissions impact on local air quality', *Air Quality, Atmosphere & Health,* vol. 6, no. 1, pp. 295-305.

Zhu, Y, Hinds, WC, Shen, S & Sioutas, C 2004, 'Seasonal trends of concentration and size distributions of ultrafine particles near major highways in Los Angeles', *Aerosol Science and Technology,* vol. 38, no. suppl 1, pp. 5 - 13.

8. Appendices

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STRUCTURED INTERVIEW INFORMATION SHEET

Relative influence of a six-lane motorway on the total daily air pollutant exposure of local residents

Please read the following before commencing the interview.

You are invited to participate in this research project on the relative influence of motorway traffic on individual's exposure to air pollutants.

The aim of the project is to determine what proportion of total daily personal exposure is attributable to being in close proximity to a major motorway. To understand this, we need to know where and how people spend their time over a typical week and whether there are any sources of pollution within their homes.

The project is being carried out as a requirement for a PhD by Woodrow Pattinson, under the supervision of Associate Professor Simon Kingham of Canterbury University and Dr Ian Longley of the National Institute of Water & Atmospheric Research (NIWA). Simon can be contacted by phone on (03) 364 2987 x7936 or by emailing simon.kingham@canterbury.ac.nz. Ian is available on (09) 375 2096 or i.longley@niwa.co.nz. They will be happy to discuss any concerns you may have about participation in the project. It should be noted that a PhD is a public document accessible via the University of Canterbury library database.

Your involvement consists of completing a short questionnaire-like structured interview which will take approximately 15 – 20 minutes of your time. You do not have to answer all questions; only those you are comfortable with. To thank you for participating, you will be entered into a draw to win a $100 Sylvia Park shopping mall voucher. We aim to have up to 100 respondents in total.

You have the right to withdraw from the project at any time without penalty, including withdrawal of any information provided. The results will be used to develop a statistical model which will help us better understand the overall influence of busy motorways on people's exposure to common air pollutants. The results may be published, but to ensure complete confidentiality, only pseudonyms will be used. Identifying information such as name and contact details for receiving a copy of your questionnaire or the study results, will be securely stored on a computer in a locked office at the Department of Geography, University of Canterbury.

The project has been reviewed and approved by the University of Canterbury Human Ethics Committee.

As the questions are based on the topic of air pollution and health, there is a risk that you may feel some discomfort in discussing possible health implications. Should you experience any distress as a result of participating in this interview, contacts for appropriate support services are provided overleaf.

INFORMATION SHEET – SUPPORT SERVICES

PSCYHOLOGICAL DISTRESS

If you are feeling concerned about your exposure to air pollution and the impact it may have on your health and wellbeing, trained counsellors are available to converse with you, free of charge.

LifeLine Aotearoa

Lifeline 24/7 Counselling: 09 522 2999 or 0800 543 354
Face to Face Counselling: 09 524 3080
Chinese Lifeline: 09 522 2088

Office Reception: 09 909 8750

PHYSICAL CONCERN

If you feel you may be physically suffering from the health effects of air pollution, this would be best discussed with your local general practitioner (GP). You may already have a preferred GP to contact or you can make an appointment with one from your Community Health Centre listed below.

Mangere Bridge Community Health Clinic

41 Coronation Road, Mangere Bridge

Phone: 09 254 4290
Fax: 09 254 4291
E-Mail: bridge.reception@mangerehealth.org.nz

Otahuhu Health Centre (Ngati Whatua o Orakei Health Services)

507 Great South Rd, Otahuhu,

Phone: 09 276 1190
Fax: 09 276 1192

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STRUCTURED INTERVIEW PARTICIPANT CONSENT FORM

Relative influence of a six-lane motorway on the total daily air pollutant exposure of local residents

I have read and understood the description of the above-named project. On this basis I agree to participate as a subject in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved.

I understand that these results will form parts of public documents but anonymity is guaranteed by use of pseudonyms only and no individual will be identifiable.

I understand that I do not have to answer any questions I am uncomfortable with.

I also understand that I may at any time withdraw from the project without penalty, including withdrawal of any information I have provided.

I note that the project has been reviewed and approved by the University of Canterbury Human Ethics Committee.

Full Name (please print): …………………………………………………………….

Signature:

Date:

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AIR POLLUTANT EXPOSURE STRUCTURED INTERVIEW

Relative influence of a six-lane motorway on the total daily air pollutant exposure of local residents

This questionnaire is divided into three sections. You do not have to answer all questions; only those you are comfortable with. We thank you for taking the time to participate.

Section 1. Participant and Household Information

1. Number of people in the home: **1a. Adults (18+):** **1b. Kids:**	**2. Smoker:** Yes/No
2a. Smoking inside: Yes/No **2b. Smoking in-vehicle:** Yes/No	**3. Gas heater/s:** Yes/No **3a.** If yes, how many hours is it typically used per day (during winter)? **3b.** Is the heater vented?
4. Gas cook top: Yes/No **4a.** If yes, how many hours is it typically used per day during winter? **4b.** Is the cooker vented?	**5. Wood burner:** Yes/No **5a. Type:** **5b.** If yes, how frequently is it lit during winter? **5c.** What fuel is typically used?
6. Occupation:	**7. Workplace suburb:**
8. Workplace type during a typical week (circle). Non-ventilated office or shop Outdoor - near traffic or industry Indoor with indoor sources e.g. workshop Transit with some on-site exposure e.g. tradesmen	**8a. Give approx. number or percent of working hours in each.** Ventilated office or shop Outdoor - countryside or quiet suburb In-transit e.g. courier driver Transit with little or no on-site exposure e.g. salesman

8b. Mixed indoor/outdoor? Yes/No **8c. Near major roadway?** Yes/No	**8d. Approx. distance to major road?**

9. Income (personal):

$5,000 or less
$5,001 - $10,000
$10,001 - $20,000
$20,001 - $30,000
$30,001 - $50,000
$50,001 or more

9a. Income (household):

$20,000 or less
$20,001 - $30,000
$30,001 - $50,000
$50,001 - $70,000
$70,001 - $100,000
$100,001 or more

Section 2. Activity and Environments over a Typical Week

This section involves loosely going through your weekly routine. You can be as specific or as broad as you want to be, provided you specify the types of environments as you go along and the approximate time spent within them. For example, it is not necessary to know the types of activities you are doing while inside at home, but you might be comfortable saying you are at squash practice or outside in the park with the kids.

1. What is your main means of commuting?

1a. If it's driving, what are your typical ventilation settings (in good weather)?

Time	0000–0600	0600-0900	0900-1200	1200-1500	1500-1800	1800-2100	2100-000
Monday							
Tuesday							
Wednesday							
Thursday							
Friday							
Saturday							
Sunday							

Section 3. Understanding and Perceptions of Air Quality

1. Do you feel that exposure to pollution from traffic, industry and home heating is bad for human heath in general?

1 – Not at all 2 – Neutral/No opinion 3 – Only slightly 4 – Fairly bad 5 – Very bad

1a. Can you name any adverse health effects which may be associated with air pollution?

2. How often do you find yourself in a **situation** where you think about the possible effects of air pollution in relation to health? This could include times such as when you notice fumes entering your car while in traffic or when a big truck goes past when you're out walking. Do not include situations when you are smoking or in a smoking area but do include situations such as being smoked out by a barbeque or outdoor fireplace.

1 – Never 2 – Once or twice per year, or less 3 – Once or twice per month
4 – Once or twice per week 5 – Daily

3. How often do you find yourself thinking about the possible health effects of air pollution from **outdoor sources**, **while at home**?

1 – Never 2 – Once or twice per year, or less 3 – Once or twice per month
4 – Once or twice per week 5 – Daily

4. How would you rate the overall cleanliness of the air at your home, while outdoors?

1 – Very poor 2 – Poor 3 – Average 4 – Good 5 – Excellent

5. How often do you find yourself thinking about the possible health effects of air pollution from **indoor sources**, **while at home**?

1 – Never 2 – Once or twice per year, or less 3 – Once or twice per month
4 – Once or twice per week 5 – Daily

6. How would you rate the overall cleanliness of the air at your home, while indoors?

1 – Very poor 2 – Poor 3 – Average 4 – Good 5 – Excellent

7. How often do you find yourself thinking about the possible health effects of air pollution from **outdoor sources**, **while at work**?

1 – Never 2 – Once or twice per year, or less 3 – Once or twice per month
4 – Once or twice per week 5 – Daily

8. How would you rate the overall cleanliness of the air outside of your workplace?

1 – Very poor 2 – Poor 3 – Average 4 – Good 5 – Excellent

9. How often do you find yourself thinking about the possible health effects of air pollution from **indoor sources**, **while at work**?

1 – Never 2 – Once or twice per year, or less 3 – Once or twice per month
4 – Once or twice per week 5 – Daily

10. How would you rate the overall cleanliness of the air inside your workplace?

1 – Very poor 2 – Poor 3 – Average 4 – Good 5 – Excellent

11. If you **live within 150 metres of a major road**, what are your perceptions in terms of how that may or may not influence your health or the health of your family?

1 – Not a worry at all 2 – Only a slight concern 3 - Somewhat concerning 3 – A moderate concern 5 – A major concern

11a. Can you elaborate on the reason/s for your choice?

12. How long have you lived at your current residence for?

12a. To what degree does traffic noise affect you while at home?

1 – Not a worry at all 2 – Only a slight concern 3 - Somewhat concerning 3 – A moderate concern 5 – A major concern

12b. If traffic noise is a concern, can you elaborate on how it affects you e.g. prevents proper sleep, disturbs the children etc.

13. If you **work within 150 metres of a major road**, what are your perceptions in terms of how that may or may not influence your health the health?

1 – Not a worry at all 2 – Only a slight concern 3 - Somewhat concerning 3 – A moderate concern 5 – A major concern

13a. Can you elaborate on the reason/s for your choice?

14. How long have you worked at your current workplace for?

14a. To what degree does traffic noise affect you while at work?

1 – Not a worry at all 2 – Only a slight concern 3 - Somewhat concerning 3 – A moderate concern 5 – A major concern

14b. If traffic noise is a concern, can you elaborate on how it affects your work day e.g. ability to concentrate

15. If you are **exposed to particularly poor air quality** while working (e.g. panel beater workshop, construction site), what are your perceptions in terms of how that may or may not influence your health?

1 – Not a worry at all 2 – Only a slight concern 3 - Somewhat concerning 3 – A moderate concern 5 – A major concern

15a. Can you elaborate on the reason/s for your choice? For example, "Not worried due to excellent safety equipment".

Thanks again for participating in the study.

Please provide a means of contact if you'd like to enter to win a $100 Sylvia Park shopping mall voucher.

Phone: ______________________________
E-mail: ____________________________________

Address:
____

I would like a copy of my interview transcript sent to me: *Yes/No*

I would like to be informed of the results of the study: *Yes/No*